**UN/ECE Task Force on Monitoring & Assessment**

under the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Helsinki, 1992)

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*Volume 2:*

# Problem-oriented approach and the use of indicators

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# Preface

This report "Problem-oriented approach and the use of indicators" is one of the four background documents to be used for the drafting of Guidelines on monitoring and assessment of transboundary groundwaters. This report has been prepared by B. van der Grift and J.G.F. van Dael (KIWA Consultancy, The Netherlands) in close co-operation with J.J. Ottens. Designated advisors for this sub-project were J. Chilton and F. Attia (Research Institute for groundwater IWACO-EMGT, Egypt).

For the execution of the overall groundwater programme a core group was established, which performed the role of guidance-committee. The core group was made up of:

| | | |
|---|---|---|
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This report was discussed and accepted by the Core Group on Groundwater, established by the ECE Task Force on Monitoring and Assessment under the Convention on the Protection and Use of Transboundary Watercourses and International Lakes.

# Contents

# 1. Introduction

### 1.1 General

The Convention on the Protection and Use of Transboundary Watercourses and International Lakes was drawn up under the auspices of the Economic Commission for Europe (ECE) and adopted in Helsinki on 17 March 1992. The Convention entered into force in October 1996 and covers, amongst others, the monitoring and assessment of transboundary waters, the assessment of the effectiveness of measures taken to prevent, control and reduce transboundary impact, the exchange of information between riparian countries and provision of public information on the results of water and effluent sampling. Riparian Parties shall also harmonise rules for setting up and operating monitoring programmes, including measurement systems and devices, analytical techniques, data processing and evaluation procedures.

In 1994, the ECE Working Party on Water Problems established the Task Force on Monitoring and Assessment of Transboundary Waters. At its eighth session in March 1995, the Working Party agreed on a phased approach to the drafting of guidelines on monitoring and assessment of transboundary waters. This phased approach means that guidelines will be drafted for rivers, groundwater, lakes and estuaries successively. After finishing the guidelines for transboundary rivers, the Working Party requested the Task Force on Monitoring & Assessment to draw up - as a second step of its activities - draft guidelines on monitoring and assessment of transboundary groundwaters.

At the first meeting of the Parties to the Convention on the Protection and Use of Transboundary Watercourses and International Lakes in Helsinki (Finland) in July 1997, an overall work-plan was agreed upon. The drafting of guidelines on monitoring and assessing transboundary groundwaters (including background documentation) was formulated as one of the activities of programme area 3: "Integrated management of water and related ecosystems". These guidelines will be considered at the second meeting of the Parties in the year 2000.

Groundwater supports various important functions. Some functions, like nature and agriculture, are directly related with the occurrence of groundwater. In other areas, like drinking water and industrial water supply, groundwater is used as a production factor, because of its normally good and constant quality. However, a high population density, continuously growing industrialisation and intensive agriculture will have a negative effect on the quality of soil and groundwater. In recent times, the soil has become polluted more and more by private and public waste dumps, air pollution, fertilisers and use of excess manure. In shallow groundwaters this pollution can easily be transported to locations where it may be harmful to other interests. These problems do not only occur within countries, but can also have transboundary impacts, which demand accountable monitoring and assessment activities. Furthermore, measures should be taken to avoid these undesired developments, within, as well as between countries with joint groundwater bodies. The integral basin area approach, or ecosystem approach, which was adopted as a basic principle in the Convention is also the basis for structuring the guidelines on monitoring and assessment of transboundary groundwaters.

As with the Guidelines on Water-quality Monitoring and Assessment of Transboundary Rivers, these guidelines are brief and concise and supported by supplementary documentation. An inventory was made of monitoring and assessment practices in ECE countries, which includes an examination and evaluation of these practices. Prior to the drafting of the guidelines, additional activities were launched to identify indicators for groundwater assessment and review the use of models. In addition, an overview of transboundary groundwaters in the ECE region was drawn up.

Co-operation has been sought with various international organisations and institutions to make the best use of existing programmes and link on-going activities in the field of monitoring and assessment.

The Guidelines on Transboundary Groundwater Monitoring and Assessment are supported by a series of 4 background documents dealing with the following themes:

1. Inventory of transboundary groundwaters
2. Problem-oriented approach and the use of indicators
3. Application of models
4. State of the art on monitoring and assessment of groundwaters

The present report is the result of the activities mentioned under number 2: "Problem-oriented approach and the use of indicators".

### 1.2 Scope and objective

This report describes the development and implementation of indicators, which can be used to attain the objectives of monitoring and assessment programs.

The scope of the sub-project can be described as follows: "In order to facilitate the management of transboundary groundwater, the information collected on the groundwater system should be condensed to indicators that are specific for different groundwater functions and uses, their problems and threats. The selection of the indicators should be based on the specific management information needs and on cost-efficiency considerations." Current practices and international developments are taken into account.

The objective of this report is to develop a guideline for a tailor-made selection and the implementation of indicators for groundwater monitoring and assessment programs and to incorporate this in the "Guidelines on Transboundary Groundwater Monitoring and Assessment".

**Definitions as used throughout this report**

- *monitoring*
  *Monitoring is the process of repetitive observing, for defined purposes on one or more elements of the environment according to prearranged schedules in space and time and using comparable methodologies for environmental sensing and data collection. It provides actual information concerning the present state and past trends in environmental behaviour. (UNEP)*

- *assessment*
  *The evaluation of the quantitative, physico-chemical and micro-biological status of groundwaters in relation to the background conditions, human effects, and the actual and intended uses, which may adversely affect human health and the environment.*

### 1.3 Outline of the report

This report describes operational indicators based on an analysis of identified groundwater problems and their specific information needs which are related to the functions and uses of the groundwater.
Chapter 2 contains theoretical aspects of environmental indicators. Firstly, it gives a definition of environmental indicators; it describes the role of indicators in the management process of groundwater systems and how to use them. Finally, international efforts concerning the development and implementation of indicators are described.
Chapter 3 deals with the problem oriented-approach for the development and implementation of indicators and the importance of a secure specification of information needs to get tailor-made indicators. A step-wise selection and development of indicators is recommended.
In chapter 4, an overview is given of the problems and information needs as reported in the UN/ECE questionnaire by the countries that have signed the Helsinki Convention on monitoring and assessment.
Chapter 5 presents examples of the step-wise selection and development of indicators for three major problems as reported in the questionnaire.
Chapter 6 contains the ‘key points’ for the guidelines for the development and implementation of indicators.

# 2. Groundwater management and Indicators

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### 2.1 Introduction

The aim of integrated groundwater management[1] is to ensure the sustainability of groundwater resources. According to the definition in the Brundtland Report in 1987, a development is sustainable when it "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Sustainability of the groundwater resources means (Van der Akker, 1997):

- durable usage;
- maintenance of intrinsic values;
- possibility to undo interferences;
- extensive control in time and space.

In order to develop and maintain sustainable groundwater resources, it is necessary to design monitoring and assessment programs to support this process. An important objective of monitoring is to gain a clear understanding of the effectiveness of the management process (controlling function). Additionally there is, detached from the definite management objectives, a need for information about the state of nature and environment (observation function).

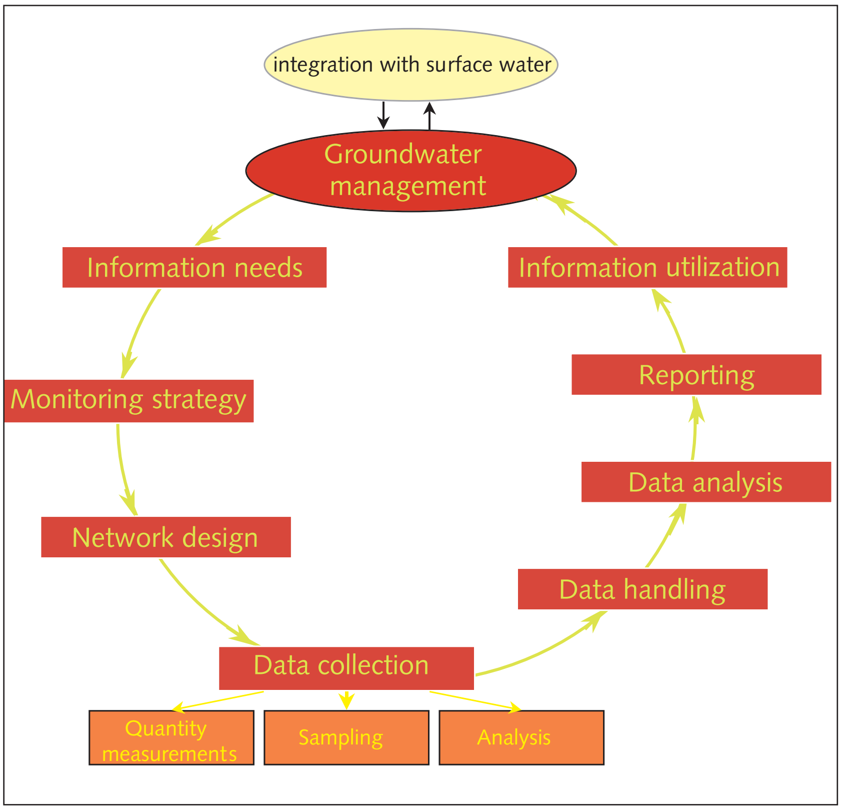
The process of monitoring and assessment can be seen as a sequence of related activities, starting with the definition of information needs and ending with the use of the information products. This cycle of activities, the monitoring cycle, is shown in figure 2.1.

Successive activities in this monitoring cycle should be specified and designed based on the required information products as well as the preceding part of the chain. In drawing up programs for the monitoring and assessment of groundwater resources, all stages of the monitoring process should be considered.

The evaluation of the obtained information may lead to new or redefined information needs, thus starting a new sequence of activities. In this way, the monitoring process will be improved. This should enhance one of the major objectives of most monitoring programs, i.e. the accurate identification of long-term trends in groundwater characteristics (UN/ECE TFMA, 1996).

**Note:**
[1] An integrated approach in groundwater management means that groundwater and surface water should be managed as a whole paying equal attention to both quantity and quality aspects; that al interactions with soil and atmosphere should be duly taken into account; and that water management policies should be integrated within the wider environmental framework as well as with other policies dealing with human activities such as agriculture, industry, energy, transport and tourism.

**Figure 2.1**
The monitoring cycle




Monitoring managers should enhance their capacity to tailor the monitoring objectives to the apparent information needs of policy makers and water management bodies and also to analyse the resulting information in a way that is relevant to policy. This will include a synthesis and appreciation of the information in an integrated way. The use of indicators and indices will help the integrated assessment as well as the specification of information needs prior to setting up monitoring objectives.
Regarding this, the question rises: "why is it not yet common practice to use indicators/indices in water management?" The main reasons are:

- there is general confusion about what indicators are;
- there is a lack of knowledge and experience on possibilities and limitations of indicators;
- the difficulty with specifying information needs alone prevents the use of indicators, since information needs must be specified before indicators are useful;
- every organisation develops its own indicators, based on their own conceptual frameworks.

### 2.2 Definitions, concepts and approaches

The word indicator derives from the Latin verb indicare, meaning (U.S. EPA, 1995): to point out, to indicate, to announce, to give notice of, to determine and to estimate. An indicator is supposed to make certain phenomena perceptible that are not, or at least not immediately, detectable. This means that an indicator has significance extending beyond that, which is directly obtained from observations. The main functions of indicators are simplification, quantification, communication, ordering and allowing for comparison of different regions and different aspects. The latter is particularly an important aspect of this project, which aims to develop a set of indicators for monitoring and assessment of transboundary groundwater. Indicators generally simplify the interpretation of the system in order to make complex phenomena quantifiable in such a manner that communication is either enabled or promoted.

Many definitions of an environmental indicator can be found in the literature. An OECD-study (OECD, 1978) concludes, that indicators are tools to:

- monitor the state of the environment and its evolution over time;
- evaluate the performance of project-programs and plans;
- communicate with the public and between decision makers;
- identify areas for action;
- help in the development of future planning procedures.

Developing a strategy for improving water quality monitoring in the United States has led to the following definition of environmental indicators (Intergovernmental Task Force, 1995):
"……measurable feature or features that provide managerially and scientifically useful evidence of environmental and ecosystem quality or reliable evidence of trends in quality " Thus, environmental indicators must be measurable with available technology, scientifically valid for assessing or documenting eco-system quality, and useful for providing information for management decision-making. Environmental indicators encompass a broad suite of measures that include tools for assessment of chemical, physical, and biological conditions and processes at several levels.

Similarities within definitions are:

- environmental indicators are observable and measurable variables or parameters or quantities;
- environmental indicators have significance beyond their face value and represent a phenomenon or (management) process in the environment. Thus, indicators have possibilities at a higher level of aggregation than ordinary parameters or variables.

From the above, it can be stated that the design and production of indicators is more than the design and production of general-purpose statistics (Bakkes et al., 1994). Statistics are seen as a necessary preliminary process, with as a possible application the production of an indicator as follows: raw data > statistics > indicators. For defining the indicator, the task is to find the appropriate level of aggregation.

The purpose of indicators is to identify the key variables within the dynamic processes of environmental change. In the OECD-study (OECD, 1978) indicators are seen as an instrument for evaluating the quality of the urban environment in order to:

- improve knowledge of the state of the environment, distribution over space and changes over time;
- evaluate actions and policies;
- improve the communication to the public.

Where the overall goal is to ensure that human beings will benefit forever from (ground)water resources, indicators are of importance in the set up of frameworks of integrated (ground)water management (Burton, 1995). After five seminars involving 125 managers from 19 countries, Burton concludes there are two major factors to account for. First, 'information limitations will force managers to seek non-traditional sources of information'. Second, 'the emphasis is on people, not technology;

institutional arrangements depend on the goodwill of those key individuals who must be convinced in order to move into action'.

Constructing a set of indicators requires a balanced approach between the information needs of decision making and the costs and constraints in order to obtain appropriate data. In the initial development of sets of indicators, the definition and understanding of concerns and needs of the population and the river basin/groundwater management precedes the definition of indicators.

River basin and groundwater management is practised in a dynamic bio-physical and social environment. An appropriate decision today on allocation and use of resources can be inappropriate under changed circumstances. Adaptive management is required to continually optimise the allocation and to promote sustainable use of resources under changing circumstances (Breen et al., 1995). Management for the sustainable use of groundwater systems compels us to develop models that can be used to predict how the system or selected components will respond to proposed management actions. Directing research by way of the development and use of predictive models has been referred to as the Predictive Model Framework for research (Bella et al., 1994). This framework has inherent limitations, because the models will always be 'simplifications of the real world'. It is recognised that a knowledge of uncertainty delivers an important contribution to the decision-making process (Reckhow, 1994). Complementary use of a 'System Response Framework' (Bella et al., 1994) has been suggested to minimise these risks. In this approach, sensitive indicators of system response are identified and monitored.

There are two general types of approaches to network design (Loaiciga et al., 1992), namely the hydrogeologic and the statistical approaches, where the latter type can be further divided into simulation, variance-based, and probability-based techniques. To compare relative advantages of each of these approaches, many factors have to be considered, including:
- the scale of the monitoring program (i.e., field-scale or regional scale);
- the objective of the monitoring program (basic/reference monitoring, detection monitoring, compliance monitoring, or research monitoring);
- the type of available data (hydrogeologic, groundwater quality, etc.);
- the nature of the investigated subsurface process (vadose zone or satured zone contamination);
- the steady-state versus transient nature of groundwater quality properties;
- the resources available to accomplish the monitoring program;
- the fact that groundwater quality monitoring network design is an iterative process.

An initial design might be upgraded as more data and resources become available. The ultimate selection of a sampling plan is often influenced, in many cases by institutional, legal and site-specific considerations.

### 2.3 International efforts concerning indicators

This section gives an inventory of on-going international efforts concerning environmental indicators in general and indicators for transboundary groundwater monitoring and assessment in particular. It describes efforts based on joint activities of different international organisations/institutions and efforts of single countries only. It tries to compare the different kind of methods of indicator research with the framework described in this report.

**European Commission**

The Directorate General XI and XII of the European Commission and Eurostat have developed some guidelines for use of environmental indicators in their Fifth Environmental Action Programme (5th EAP). They have two approaches:

- satellite accounts (physical and monetary; in Gross National Product terms);
- development/calculation of physical indices related to pressures of human and economic activities on the environment.

In the 5th EAP only pressures are monitored. A system of environmental pressure indices has been developed for this (see table 2.1):

- pressures change the state, which will lead to a social response (or lack of), which may in turn lead to reduced (or increased) pressure;
- pressures are linked to 10 policy fields which cover the items of the 5th EAP.

**Table 2.1**
10 policy fields of the 5th EAP with accompanying pressure indices.

| Policy field | Pressure indices | Policy field | Pressure indices |
|---|---|---|---|
| Climate change | $CO_2$ emission | Waste | Landfill area<br>Hazardous waste |
| Ozone layer depletion | Halon emission | Air pollution | |
| Loss of biodiversity | Pesticide use<br>Fragmentation index | Marine environment & coastal zones | |
| Resource depletion | Fossil energy use | Water pollution & resources | Groundwater extraction<br>toxic discharges |
| Dispersion of toxins | | Urban problems, noise & odours | |

**Canada**

Canada is in the process of developing indicators which will provide a comprehensive picture of the state of the environment and indicate trends towards the environmental goals of sustainable development. A preliminary set of indicators divided predominantly by environmental media, was published in 1991, with individual indicators reflecting environmental stresses and the state of the environment for particular policy issues (e.g. climate change, ozone depletion and freshwater quality) (Environment Canada 1991). Since 1992, a series of indicator bulletins have been published which present key indicators for particular environmental issues and illustrate the complexities and cyclical nature of environmental systems. For example, the indicator bulletin for stratospheric ozone depletion describes the environmental route of ozone-depleting substances and presents data for three indicators 'domestic supply of ozone-depleting substances', 'global atmospheric concentrations of CFC-11 and CFC-12' and 'stratospheric ozone levels over Canada'. According to the PSIR-concept, the first mentioned indicator is a pressure indicator, the second a state indicator and the last an impact indicator.

**Great Britain**

In Great Britain, the lack of suitable state indicators is recognised as a limitation of the existing groundwater quality monitoring (Chilton and Foster, 1997). Indicator parameters such as biochemical oxygen demand, dissolved oxygen (DO), ammonia and faecal coliforms have been used in surface water monitoring for many years. They are used as a basis for various indices of river quality and in setting and evaluating Water Quality Objectives for rivers. The use of indicators is less well developed for assessing groundwater quality than for surface water. In groundwater, the use of indicators that provide a general picture of the "health" of the aquifer is attractive, but at present it is not easy to choose suitable indicator parameters for groundwater. Possible candidates include electrical conductivity, dissolved oxygen, pH, alkalinity, chloride and nitrate, and possible total or dissolved organic carbon (TOC/DOC). Edmunds (1996) gave a preliminary review of the scope for the use of suitable state indicators in groundwater systems, see Annex 1.

In addition, the multi-objective nature of most groundwater quality assessments, the dominance of potable supply use and the statutory and legal framework in which assessments are undertaken, mean that extensive groups of parameters are usually required. The only objective of groundwater quality assessment, which has been successfully met in some instances by an indicator, is the use of electrical conductivity to monitor saline intrusion.

**United States**

The U.S. Environmental Protection Agency has made many efforts in developing environmental indicators for water quality (U.S. EPA, 1995). To achieve environmental progress and to develop a set of useful indicators, the U.S. EPA has adopted specific water objectives to guide its water management and assessment programmes. These goals and sub-goals are subsets of, and support to, the two national water objectives: Clean Waters and Safe Drinking Water. The water goals from the U.S. EPA are delineated in figure 2.2. These goals are like building blocks in a pyramid, where success in reaching the goals at the top depends on successful attainment of those lower in the pyramid.

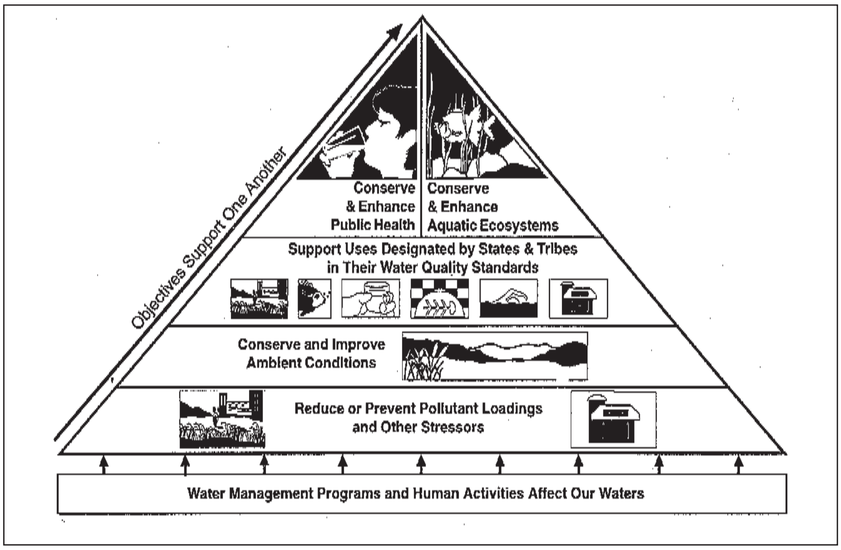
The U.S. EPA described an indicator as a tool to measure progress towards a goal. They distinguish between three kinds of goals in management objectives for water:

- national goals described in the Safe Drinking Water Act and the Clean Water Act;
- water subgoals, the building blocks in figure 2.2;
- milestones for 2005, this is a specific milestone that defines where the U.S. EPA wants their water resources to be in the year 2005.

The U.S. EPA monitoring and assessment programmes do not distinguish between surface water and groundwater. Indicators developed by the U.S. EPA concerning groundwater are given in Annex 2.

For example, by reducing pollutant loads to waters, the overall quality, or ambient condition of the water and sediment will improve (this is a sub-goal). Consequently, the waters will have an enhanced ability to support the function for which they were intended (this is a goal). Ultimately, the health of both the general public as well as aquatic ecosystems is protected. In other words: by reducing the pressure on the water system, the state will improve and the impact will meet the standards of the intended function. Prevention, remediation and restoration programmes (social response) aim to achieve these goals. This EPA-concept described an indicator as a piece of information to measure the progress towards the U.S. national goals and sub-goals.

**Fig. 2.2**
The U.S. Environmental Protection Agency-concept (U.S. EPA, 1995)




Attia (1996) and Driessen and Viergever (1996) also use a concept similar to figure 2.2. In their research on environmental indicators, they use building blocks in a pyramid for the interpretation of water quality data. From bottom to top, the building blocks contain:

- important parameters;
- representative indicators;
- aggregated indicators (indices);
- links to describe sustainable development.

The EPA-concept does not make clear that there is a feedback from the impact objective (Clean Waters and Safe Drinking Water) to the socio-economic system (Water Management Programmes and Human Activities Affect Our Waters). The EPA concept is a one-way framework. It suggests that there is only an information flow from the bottom of the pyramid to the top, while in reality the kind of water management programs and human activities are originally influenced by the condition of the environment.

**Egypt**

Groundwater is becoming increasingly important in Egypt's water policy. As a first step in the protection of this resource, the Research Institute for Groundwater of the Egyptian Ministry of Public Works and Water Resources conducted a preliminary research (trial) for the selection of groundwater quality indicators (Attia, 1996). Attia suggested that the development of indicators should be based on various factors, namely:

- water quality issues;
- impacts on the specific use of water, including health, industrial and agricultural production, etc.;
- participation of the public (affected and affecting community);
- availability of time series of records.

Due to the lack of time series concerning groundwater, reference has been made to the results of a consultation conducted by a group of Egyptian experts (box 2.1). The indicators selected by the group of experts were based on a quantitative risk assessment of exposure probabilities to sensitive populations and calculated numeric values of the risk of specified consequences. Seven potential water quality hazards were evaluated in terms of their effect on public health, agriculture and environment. The identified indicators represent surface water quality hazards, evaluated on regional water quality data (Nile water) as well as professional judgement.

**Box 2.1**
List of indicator parameters based on the seven highest potential surface water quality hazards in Egypt (Attia, 1996).

- Parasites, pathogens, and viruses (E.Coli)
- Nutrients (nitrate, phosphorus)
- Trace metals (trace metals)
- Salinity and physical properties (salinity)
- Oil, grease, and petrochemicals (BOD, COD and Oil & Grease)
- Pesticides and insecticides (pesticides)

They are listed according to priority (scoring).
Attia modified the list of indicators identified by experts (see box above) to suit the groundwater environment.
The main indicators identified for groundwater quality in Egypt are:

- Salinity
- Nitrogen
- Trace metals
- Faecal Coliforms

If the demand exceeds the recharge, there will be more salinity problems, thus salinity indicates quantitative problems. Nitrogen indicates the pressure on the groundwater system from agricultural sources, trace metals from industrial sources and faecal coliforms from human sources. The institute will develop final indicators as soon as additional information is made available from the water quality monitoring system. It is worth mentioning that groundwater indicators developed by Attia are based on the use of groundwater for drinking water (highest quality requirement) because the policy of the government is to give priority of groundwater allocation to potable water.

# 3. The problem-oriented approach

### 3.1 Introduction

In the first paragraphs of this chapter (3.1-3.4) some theoretical background is given on approaches and conceptual frameworks that will help to develop, select or implement tailor-made indicators. The later paragraphs (3.5-3.7) give a more practical guidance with selection criterion, stepwise-approaches and linkage with a recently developed methodology to specify information needs that can be used to set up any information collection system like for example monitoring.

The most critical step in developing a successful, tailor-made and cost-effective monitoring program is the clear definition and specification of information needs. Information needs should have a clear linkage with the monitoring objectives. Information needs and monitoring objectives must be specified to such an extent that design criteria for the various elements of the information system can be derived (UN/ECE TFMA, 1996).

In the initial development of sets of indicators that are problem oriented, the definition and understanding of concerns and needs of the population and the river basin/groundwater management precedes the definition of indicators. The specification of information needs is often a difficult task. In the past, many monitoring programs have been characterised by the "data rich, but information poor syndrome". The data collected in monitoring must usually meet the multiple objectives and information requirements of more than one organisation. Attention should be directed towards the end product of monitoring, i.e. information. Therefore, it is important to specify the use of information while thinking about what information is needed. An important step in the specification of information needs is to distinguish possible uses of information (CIW/CUWVO, 1996):

- Information for policy preparation: Information for future developments is needed. Major sources are experiences, also from other parts of the world, and extrapolation of developments.
- Information for operational water management: Essential is the possibility to react instantly.
- Information for policy evaluation: This information is linked to the policy as defined. The starting point is the existing or desired function and resulting information should show to what extent problems are still relevant and what effect measures have had.

The information needs can be translated into general objectives of monitoring and assessment programs for groundwater. Examples of monitoring objectives are presented in Table 3.1 (Chilton and Foster, 1997). Dependent on the situation at a certain location other monitoring objectives can be defined.

Table 3.1
Objectives of groundwater monitoring and assessment programmes (Chilton and Foster, 1997).

| Objectives | Information Output |
|---|---|
| Trends | Show trends of groundwater quality and or quantity changes derived from natural causes, the impact of diffuse pollution sources and changes in hydraulic regime. |
| Baseline for future issues | Provide background information on groundwater quality so that the impacts of future, as yet undefined, human activities can be detected. |
| Spatial distribution | Provide a picture of the three-dimensional distribution of groundwater quality within aquifers. |
| Early warning | Provide early warning in recharge areas of the impacts of diffuse sources of pollution. |

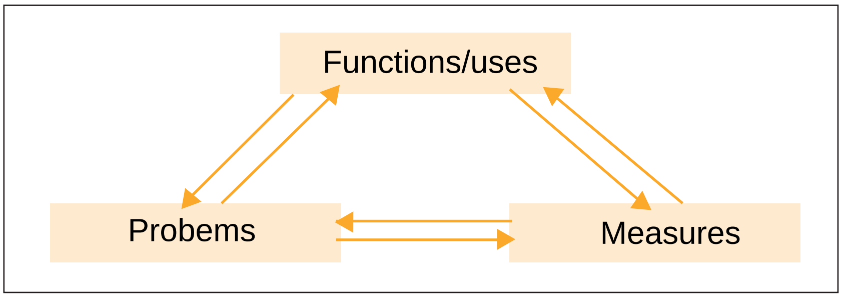
Since most indicators will be linked to functions and uses, they can be used to prioritise different needs or to integrate requirements linked to the different functions/uses. Therefore they can be very helpful when specifying information needs (Ottens et al, 1997).

### 3.2 Specification of information needs

The development and implementation of indicators in monitoring and assessment programs should be based on the core elements in the management of groundwater systems and on the active use of information in the decision-making process. These elements can be defined as the functions/uses of the groundwater system, the issues (problems) and pressures (threats), and the impacts of measures on the overall functioning of the groundwater system. The core elements in water management and their interactions are shown in figure 3.2 (UN/ECE TFMA, 1996). A full picture of the situation only becomes clear when the information in all three corners of the triangle is dealt with.

A first, easy step is to specify the relevant functions and uses of the groundwater. By analysing the requirements of water quality and quantity for each function or use, a first idea of the needed information is obtained (Timmerman and Ottens, 1997). The next step is to describe the issues, which pose a threat to the sustainable use of groundwater for the specified functions/uses. The confrontation of functions/uses with issues gives insight into the measures to be taken.

Fig. 3.2
The core elements in water management (UN/ECE TFMA, 1996)




#### 3.2.1 Functions and uses of groundwater

Groundwater systems comprise different functions. Dependent on these functions different demands on the quality and/or quantity of the groundwater will be made. The functions of groundwater can be classified into three categories (see table 3.2) (Buis and Dogterom, 1995). Category "0" contains groundwater functions without demands, like the storage of energy in groundwater. For category 1, in contrast with category 0, the quality of the groundwater is important. The functions require a defined minimum quality. This category contains functions like drinking water and irrigation. In category 2, the ecosystem takes a central position. For this function, requirements on the quality and the quantity of the groundwater have to be accomplished. Considering the functioning of the ecosystem, the water quality and quantity demands can be formulated as "no-effect-levels".

**Table 3.2**
Functions of groundwater systems, classified in three categories, dependent on the quality and quantity demands.

| Category | | Function |
|---|---|---|
| 0 | Functions without quality demands | (Storage of) geothermal energy |
| 1 | Functions with a minimum quality | Drinking water supply<br>Industrial water supply<br>Agricultural water supply |
| 2 | Functions with "no-effect-levels" quality and quantity demands | Ecosystems |

### 3.2.2 Issues

Different groundwater problems and threats will have greater or lesser importance in different regions or countries, but this does not negate the advantages of working with a common international list of environmental issues.
To solve environmental problems, the Dutch government has developed a set of water quality and water quantity issues (NMP, 1989). For the groundwater system those issues are:
- excess nutrient loads;
- acidification;
- spreading of chemical substances (organic compounds, heavy metals);
- desiccation;
- salinization.

The issue acidification comprises the flux-increase of acidifying substances, which can result in a lowering of the pH or a decrease of the Acid Neutralising Capacity (ANC) or the alkalinity of groundwater.
Excess nutrient loads are the enrichment of water with too many nutrients, particularly nitrogen and phosphate. It causes eutrophication of surface waters.
The issue spreading of chemical substances refers to antropogenic pollution of groundwater i.e. by heavy metals or other toxic substances leading to increased concentrations of these substances in the environment.
Hydrological interference like groundwater withdrawal, river bed correction and dam construction leads to a lowering of groundwater tables and loss of wetlands.
Salinization is the phenomenon whereby water is enriched in major ions. The total amount of dissolved solids, as well as specific ions, like fluoride, chloride, sodium and potassium can have effects on the functions of the groundwater.
The mentioned groundwater quality and groundwater quantity issues were developed for the Dutch situation but they can also be applied to the groundwater situation of many other European countries. The reason for this is that the sources of environmental pollution are more or less the same in most countries.

The main sources of groundwater pollution are:

- impact from agriculture;
- impact from existing point- and non point -sources of groundwater pollution;
- impact from groundwater withdrawal;
- impact from old waste-disposal sites;
- impact from decommissioned industrial areas;
- impact from former/existing military sites;
- sea water intrusion.

### 3.2.3 The function-issue table

A classification of groundwater problems and threats in relation to functions and uses is an important management step towards sustainable groundwater resources. Water quality and water quantity can be judged by standards, which are based on the functions/uses of the groundwater. This is an important benefit of classifying functions. In a non-classified, multi-functional approach of groundwater management, all groundwater systems have to fulfil the highest composed quality and quantity standard, even when those high standards are not necessary for the particular use of the groundwater.

After classification of the issues and functions of the groundwater system, the next step is to link these with each other, in order to identify which combination of issues and functions conflict with each other. This linkage is given in Table 3.3: the function-issue table. A "*" in Table 3.3 means that the function of the groundwater system is conflicting with the pressures caused by the matched issues.

**Table 3.3**
Link between functions and issues of groundwater systems.

| | Functions | | | |
|---|---|---|---|---|
| | drinking water | industrial water | Agricultural water | Nature |
| Acidification | * | | | * |
| Excess nutrients | * | | | * |
| Spreading | * | * | * | * |
| Salinization | * | * | * | * |
| Desiccation | * | * | * | * |

## 3.3 Conceptual frameworks

### 3.3.1 Introduction

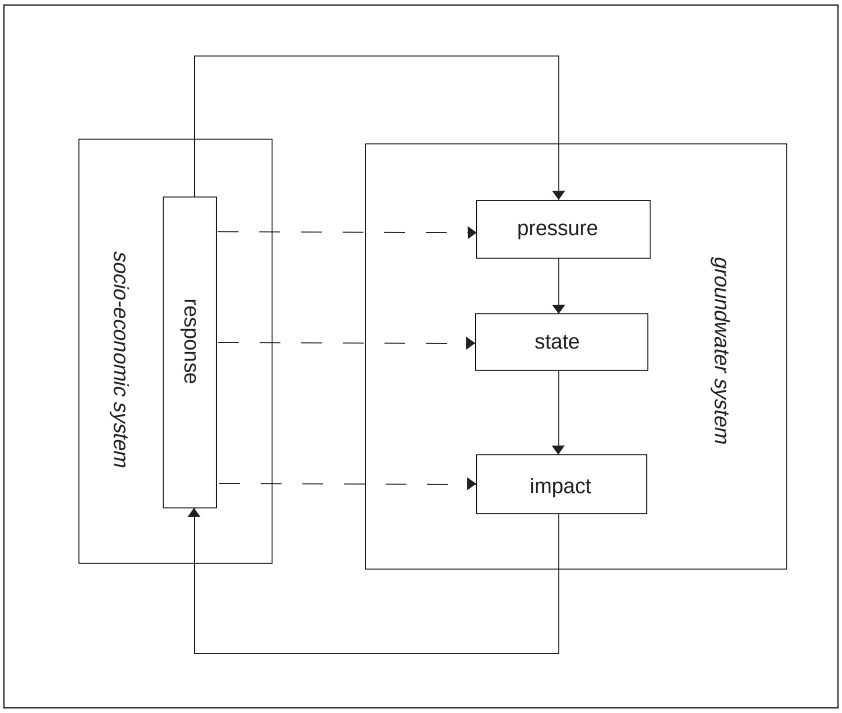
The discussion on monitoring and assessment of groundwater systems and the selection of tailor-made indicators could be based on conceptual models, which will lead to a better understanding of the meaning and use of indicators. A conceptual model is a verbal, or visual abstract description of a part of the world from a certain point of view. It is important that the model is described in words or pictures. Such a model facilitates communication within a group by providing a conceptual structure, by indicating boundaries and by providing a framework for further expansion (Bakkes et al., 1994).

Conceptual modelling is useful because it closely follows the way in which experts and managers think and it prescribes a structure that is flexible enough to express many possibilities. The drawback of conceptual models is that the suggested linear relationships might obscure the more complex relationships in ecosystems and the interactions of the other sub-systems with the environment (such as the groundwater system and the socio-economic system). In the problem-oriented approach, there are two more conceptual models used besides the function-issue-table for further specification of the information needs.

### 3.3.2 PSIR-concept

Harten et al. (1995) have developed a framework which can be used to describe environmental management of water systems. This so-called Pressure-State-Impact-Response-concept (PSIR) is represented in figure 3.3. The PSIR-concept has two objects: the socio-economic system and the groundwater system. The groundwater system consists of three sub-objects: the pressure, state and impact-systems. The pressure-system shows that the human activities concerning a (ground) water system can cause changes in quantity and/or quality of the water, which means a new state. The impact of changes in state can influence the function or use of groundwater. It is likely that there will be a human response, aiming at a new balance of the (ground)water system and protection of functions and uses. Possibly the human response is to reduce the pressure, but also the state or impact on the groundwater system can be influenced.

**Fig. 3.3**
The Pressure-State-Impact-Response-concept (Van Harten et al., 1996)




The state and impact sub-objects are in some cases nearly the same or overlap each other. The impact-sub-object is the state-sub-object that considers the function attached to the groundwater system. The OECD (Organisation for Economic Co-operation and Development) for example takes both systems together in the state system (OECD, 1993).

The PSIR-concept can be used for further specification of information needs and research on indicators for groundwater monitoring and assessment. For each sub-object in the framework, it is possible to select and describe specific indicators.

**Pressure indicator**

A pressure indicator describes quantitatively the activities within the socio-economic system which affect the condition of the groundwater system. It contains the source of environmental stress: indirect and direct pressures. Direct pressures are, for example, emissions or discharges of pollutants. Indirect pressures are related to socio-economic issues, such as population growth and economic development. Pressure indicators have to be sensitive for environmental stress and have a quick response. The pressure indicator can also be used as an early warning indicator for groundwater issues. For example in many European countries atrazine has been withdrawn from use for non-agricultural purposes (roads and railways) and the compounds which are used instead are now beginning to appear in groundwater.

The pressure indicator is important for the policy makers at the ministerial level. The policy makers have to develop a policy in which there is no threat for the function of the groundwater, due to a certain activity.

**State indicator**

State indicators are physical, chemical and biological parameters, which describe the situation of the groundwater system in a qualitative and/or quantitative way. The state of the groundwater system is dependent on the pressure and the vulnerability of the system. The state indicator is an important indicator for policy makers, planners and managers who are responsible for the preparation of decisions and their implementation at the catchment scale.

**Impact indicator**

An impact indicator is a state indicator that considers the function of the groundwater. Impact indicators give information about the effects of the pressure expressed as a change of the state indicator and are related to the function attached to the groundwater system (the water quality and/or quantity demands which are used to guarantee the sustainability of the concerning function). The impact indicator can be expressed in different units, like the volume of a specific source, percentage of the total available groundwater systems, fraction of the total amount of groundwater which satisfies the demands of a specific function, loss of yields (agriculture), increase of health risk or cost of maintaining the function of the groundwater system.

**Response indicator**

A response indicator represents the social reaction to the environmental stress. A response indicator contains the measures which society takes to improve the environment. These can be individual or collective actions to reduce or avoid undesirable effect on the environment. Societal response indicators can measure regulatory action, environmental or research expenditures, public opinion and consumer preference, change in management strategies, and the provision of environmental information (Rump, 1996).

**Example**

An example of the PSIR concept can be given for the influence of liquid manure on the groundwater system and the use of groundwater as a source of drinking water. Thus, as an indicator for the pressure on the groundwater system, the nitrogen load of the soil (kg/ha/yr) can be chosen. The NO3-concentration in shallow groundwater can be selected as an indicator for the state of the system. An impact indicator can be the proportion of groundwater which is suitable as a source of drinking water without special treatment. A response indicator could be, for instance, the percentage of the total amount of produced liquid manure which is processed in a way that is not harmful to the environment.

The function-issue table of the previous paragraph (table 3.3) can be linked to the PSIR-concept. This indicator framework can be filled up with pressure-, state-, impact- and response indicators for different combinations of functions and issues (see figure 3.4).
In figure 3.4, the threats to groundwater systems are summed up in vertical order, and the type of PSIR-indicators in horizontal order. The function of the groundwater is given in a third dimension. The indicator framework is a very useful tool for the selection and use of indicators for monitoring and assessment of transboundary groundwater.

**Fig. 3.4**
Issues for which indicators could be developed, using the PSIR-concept.

*Ecosystem*

*Agricultural water use*

*Industrial water use*

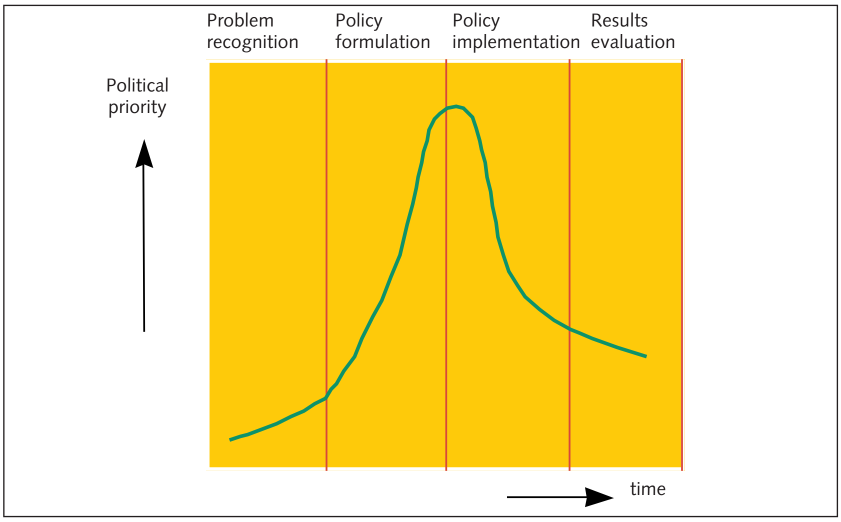
*Drinking water supply*

| | **Pressure** | **State** | **Impact** | **Response** |
|---|---|---|---|---|
| Acidification | | | | |
| Excess nutrients | N-load on farms | Nitrate in ground-water | Nitrate in drinking water | Control of manure/ fertiliser use |
| Dispersion of hazardous substances | Lead water pipes | Pb in drinking water | Pb in human blood | PVC/PE water pipes |
| Declining GW-tables | Drinking/ industrial water demand | Declining water tables | Loss of yields | Control of abstraction.<br><br>Artificial recharge |
| Salinization | Over-exploitation | High Chloride concentration | Impairment of drinking water quality | Artificial recharge |

### 3.3.3 Policy life-cycle concept

According to Winsemius (1986), within environmental problems (for instance issues concerning groundwater systems) four stages are practically always distinguishable: problem recognition, policy formulation, policy implementation- and results' evaluation. In the first stage, the question for discussion is whether there is a true environmental problem. There is probably much discord among politicians, or between politicians and the public. With growing sight on the problem, admission grows and there is less discord and more agreement on the political weight of the problem. The second stage is a policy formulation stage, which will lead to a solution of the problems. Political weight is high, due to the focus of the public on the problem solving capacity of the politicians. In the third stage, the policy is implemented and measures are executed to solve the problem. The fourth stage is characterised by the control of the solved, or nearly solved, environmental problem. In figure 3.5, the four stages of the policy-lifecycle are outlined against their political weight.

**Fig. 3.5**
Policy life-cycle (after Winsemius, 1986; Cofino, 1995)




When using the policy life-cycle concept in environmental management, it is necessary to develop indicators for different stages. Within a given problem area such as groundwater pollution, the desired type of indicator will change over time and so will the type of data required. The first and second stages require rough data to recognise the problem and the causal coherence. The third and fourth stages require more precise data and operational indicators to select the most effective measures and to quantify their effect. The different policy stages and indicator requirements are given in table 3.4.

**Table 3.4**
Survey of different kinds of indicators in relation to the management life-cycle concept
(after Heij and Bannink, 1995)

| **Management stage** | **Demands of the indicator** |
|---|---|
| Problem identification | Sensitive to stress, quick response, shows trends over a long time |
| Policy development | Possibility to evaluate and to make prognosis of cost/profit analy-sis of different policy-options |
| Policy implementation, control and evaluation | Possibility to compare the present situation with the target situation |

The policy life-cycle is a suitable framework to help with the development and implementation of groundwater monitoring and assessment programs. This concept clearly gives a very good distinction between the two target groups of this project (described in users of information). The first and particularly the second stages of the policy life-cycle concept (admission and policy formulation) concern policy makers. The second two stages (solution and control) concern managers on an operational level.

### 3.4 Similarities and differences in the use of conceptual models

The previous section presents three concepts for the development of indicators e.g. the function-issue-table, the PSIR-concept and the policy life-cycle. All three of them are used for the specification of information needs and the development of tailor-made indicators for groundwater management. The similarities and differences of these concepts are shown in table 3.5.

**Table 3.5**
Common selection criteria for indicators (Indicator Branch, 1994)

| Function-issue-table | PSIR-concept | Management lifecycle |
|---|---|---|
| First impression of information needs<br><br>Links information needs to standards which indicates fitness for use of groundwater resources<br><br>*Catchword*: fitness for use | Further specification of information needs<br><br>Links information needs to nature and origin of environmental problems that stresses the fitness for use of groundwater resources<br><br>Combined with the function-issue-table gives an indicator framework<br><br>*Catchword:* causality chain | Further specification of information needs<br><br>Links information needs to decision making process (management level) and execution of measures (operational level)<br><br>*Catchword:* management and problem solving |

### 3.5 Stepwise selection and development of indicators

Rather than recommending the use of specific indicators (because they are time and place dependent), the aim is to propose a method for selection of indicators which can be successfully used in monitoring and assessment of transboundary groundwater. Monitoring objectives such as trend detection, baseline information, spatial distribution and early warning should have a clear connection with information needs. Therefore, the following stepwise selection is recommended:

1. Identify functions/uses (like drinking water supply) and issues (problems and threats like acidification and desiccation) of the groundwater system.
2. Compare functions and issues (the function-issue table) to get a first impression of bottlenecks. If the impact of the issues is conflicting with the function of the groundwater system, management objectives should be formulated to protect these groundwater resources. When budgets are restricted, a function-issue table can be used as a tool for priority setting.
3. Use the PSIR-concept for further specification of information needs. The system approach of this concept is helpful in finding casualties between environmental problems (pressure), the impact on groundwater resources (impact, state) and measures to be taken (response).
4. Tailor the indicators on the organisational level, by using the policy life-cycle. Information needed for policy making differs from information needed for evaluation of restoration measures. The life-cycle of the problem is indicative for the indicator choice and data gathering.
5. Collect at least the following information on place and time dependent factors:
   - The hydrological and geochemical functioning of the groundwater system
   - The users of information (policy makers and/or managers on operational level)
   - The stage of the management (problem-assessment policy forumulation, policy-implementation and control)
   - The available (technical and financial) means.

6. Make a checklist with criteria that the indicators have to fulfil and choose or develop indicators.

### 3.6 Collection of information for selection and use of tailor-made indicators

To enable successful implementation of tailor-made indicators in groundwater monitoring and assessment programs, a lot of information is needed. The information needed before making a choice of which indicators to use can be summarised in a few questions (partly after Heij and Bannink, 1995):

- How does the groundwater system work?
  - What are the spatial and temporal scales of the groundwater system?
  - Are there chemical, physical and biological processes?
- Who are the users of information?
- What are the available (technical and financial) means?

**Spatial and temporal scale**

Environmental problems exist on different geographical scales, from local to global. Information has to match the level on which a problem takes place. Global problems, like climate change, require a global analysis and global indicators. Figure 3.6 shows the general relationship between possible indicators, environmental issues and ecological processes at various scales. There is an obvious overlap among the issues at different scales with higher level issues pervading all lower levels. National and regional indicators can only be developed by recognising this geographical context. Groundwater systems and the problems threatening them (like excess nutrient loads and acidification) exist on local, regional or national scales. An additional scale is necessary when dealing with transboundary groundwater systems. Harmonisation of indicators on both sides of the borders is required.

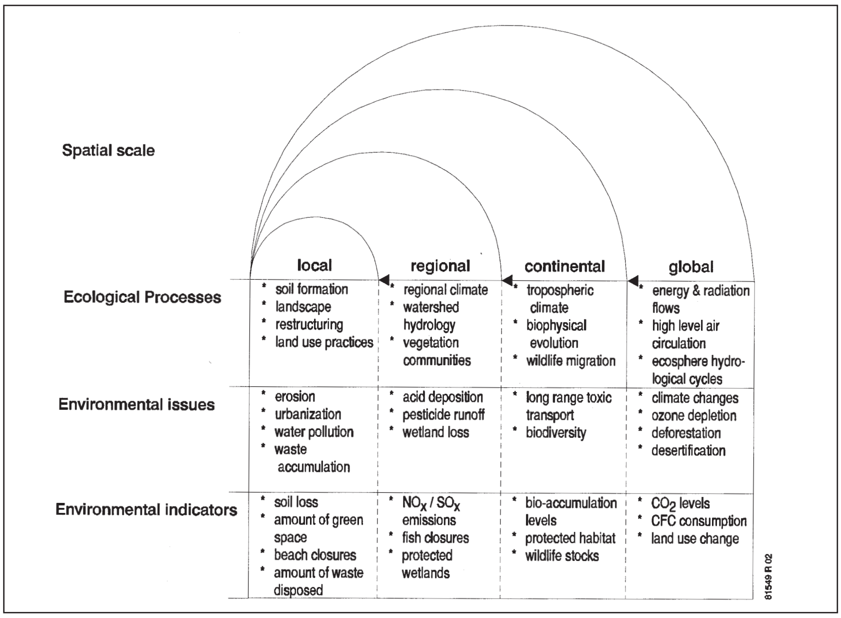



**Fig. 3.6**
Spatial scales, ecological processess and indicators (Rump, 1996)

There is a clear difference in time scale between surface water and groundwater. In comparison with surface water, groundwater runs very slow, which means that residence times in groundwater can be orders of magnitude higher than surface water and the water quality changes slowly

(Figure 3.7). Surface waters are more vulnerable to pollution than groundwater systems. In groundwater, the risk of long term pollution is much higher (Claessen, 1996). Within groundwater systems, there is a big difference between the age of the water (Figure 3.7). Aquifers (water bearing layers) containing old water are less vulnerable to pollution in comparison to aquifers containing relatively young water.

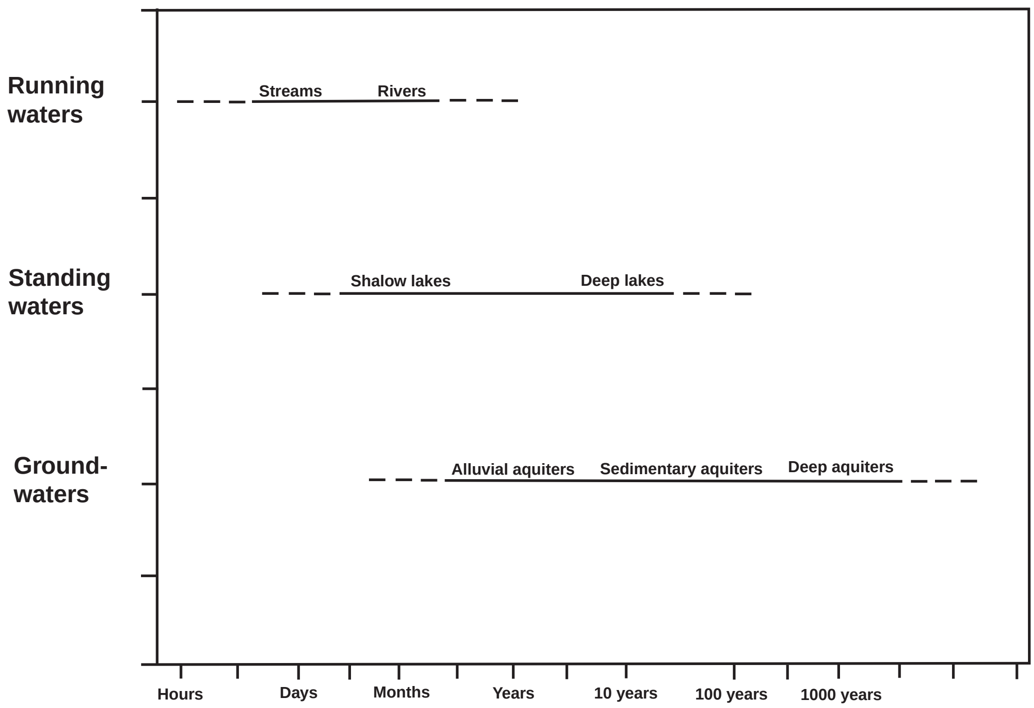



**Fig. 3.7**
Water residence times in freshwater bodies (Meybeck et al, 1989)

**Chemical, physical and biological processes**

Groundwater systems are complex systems, in which all sorts of chemical-, physical- and biological processes take place. For the selection of indicators it is necessary to have knowledge about the processes in groundwater systems. The occurence of these processes mostly depends on the geochemical and hydrological situation of the aquifer. As the water moves, reactions, including dissolution, oxidation and reduction, ion exchange and precipitation modify the major ion and trace constituent composition of the groundwater. As a result, even the "baseline" quality of groundwater is subject to spatial variations, which must be appreciated before the superimposed impacts of human activities can be detected and quantified.

For example, the impact of nutrient loads to groundwater due to excess manure spreading can be monitored and nitrate can be used as an indicator. The process of denitrification[2] will occur when the soil contains a certain percentage of organic matter and/or a shallow groundwater table (Baggelaar and Van Beek, 1995).

**Note:**
[2] The chemical reaction of nitrates (NO3) with soil-organic-matter or pyrite (FeS2) to nitrogen-gas (N2) and bicarbonate (HCO3).

**Users of information**

The users of groundwater information are, based on the Helsinki Convention, distinguishable in two groups: policy makers and managers at the operational level. Each of these groups requires its own kind of information. The first group comprises the decision-makers at the ministerial level, those who need guidance on issues to be included, or taken up by international agreements on transboundary groundwater. Objectives such as "sustainable development" play an important role in the formulation and evaluation of policy. Policy makers need information which gives insight into the state of the transboundary groundwater system in terms of sustainable development and the information must be easy to read.

The second group comprises the planners and managers of transboundary groundwater systems, the people who are responsible for the preparation of decisions and their implementation at the catchment area level (i.e. regional and local authorities). These planners and managers at the operational level need information to evaluate and to make prognoses of the water quality and/or quantity issues and to compare the present situation with the target situation.

**Available means**

Last but not least, the available technical- and financial means must be considered. Indicators should be easy to measure or obtain and also be reasonably cheap.

## 3.7 Criteria for indicator selection

Environmental indicators should be able to satisfy predetermined selection criterion to ensure their viability (Intergovernmental Task Force, 1995). These criteria provide a series of guidelines that shape the decision making process, which results in an indicator that meets the needs of the program. It is important to put the selection criterion into a standardised format, that can be useful for nation-wide programs.

The Indicator Branch of Environment Canada (1994) has reviewed the selection criterion used by several countries and organisations such as Norway, the Netherlands, Canada, the United States of America, UNEP and OECD. They have made a list of selection criterion that were commonly found in literature, often referred to, and use similar terms. A general definition of the commonly used criterion was given, together with a list of synonyms used. The list of common selection criterion (table 3.6) are categorised by 'usefulness to decision-makers', 'issue relevance' and 'data reliability'. The list of criterion with definitions can be found in Annex 3.

**Table 3.6**
Common selection criteria for indicators (Indicator Branch, 1994).

| Usefulness to decision makers | Issue Relevance | Data reliability |
|---|---|---|
| Understandable | Scientific validity | Geographic coverage |
| Relevant | Representative | Cost-effective |
| Target/threshold | Responsive to change | Data adequacy |
| Potential for comparison | Predictive | Data availability |

The study also reviewed the process of developing indicators and how selection criterion are applied. Their main conclusions were the following: Between authors and organisations, there are some common goals and selection criterion. There is a dual emphasis on: 1) reliable information on the environment (i.e. data reliability and issue relevance), and 2) information that is useful for decision-makers, depending on the user. A hierarchy of criterion from general to specific can be detected. The general criterion tend to be more related to the goals of indicator development, while specific criteria tend to be more related to technical implementation.

When selection criterion for indicators are specified, these criterion have to be evaluated after implementation of the indicators. This is a difficult task because there is no specification given how to evaluate the indicators in terms of ability to fulfil the criterion, nor how the criterion relate to each other in terms of priority.

# 4. The Core Group Questionnaire and reported problems

This chapter deals with the results of the questionnaire developed by the core group on groundwater. The questionnaire was sent to the ECE-countries which have signed the UN/ECE treaty of the "Convention on Protection and Use of Transboundary Watercourses and International Lakes" (UN/ECE, 1991).

Besides general questions about groundwater resources, the questionnaire also contained some additional questions for the sub-project "problem-oriented approach and use of indicators":

1. Which functions and uses can be distinguished in the groundwater system?
2. Which problems may occur? (pollution, demand larger than recharge, desiccation of wet ecosystems and management problems related to conflicting uses of groundwater)
3. What are the management objectives for these groundwater systems?
4. Which information is needed in order to evaluate the management objectives?
5. Are indicators used? Can these indicators be related to the described functions and problems of the groundwater system and also to the management objectives and/or information needs?

### 4.1 Countries that responded

Twenty countries replied to the questionnaire. From figure 4.1, it becomes clear that these countries are mainly countries in Eastern Europe or former Soviet-Union countries. Countries that have done the most research on indicators, like Denmark and Sweden, have not signed the treaty of the Helsinki-Convention and are not mentioned. An overview of the responses to the above-mentioned questions is given in Annex 4.

### 4.2 Functions and uses

In all ECE-countries which have replied, groundwater is used as a source of drinking water supply and industrial water supply (figure 4.2). In most of the countries, groundwater is also used for agricultural water supply. These are all category 1 functions. Category 1 functions are functions with only a minimum quality demand. Half of the countries have attached an ecological function (shallow groundwater for wet ecosystems) to the groundwater (a category 2 function). Other given functions of groundwater are thermal-spa, geothermal energy and production of substances (e.g. iodine).

**Figure 4.1**
Countries that responded to the questionaire

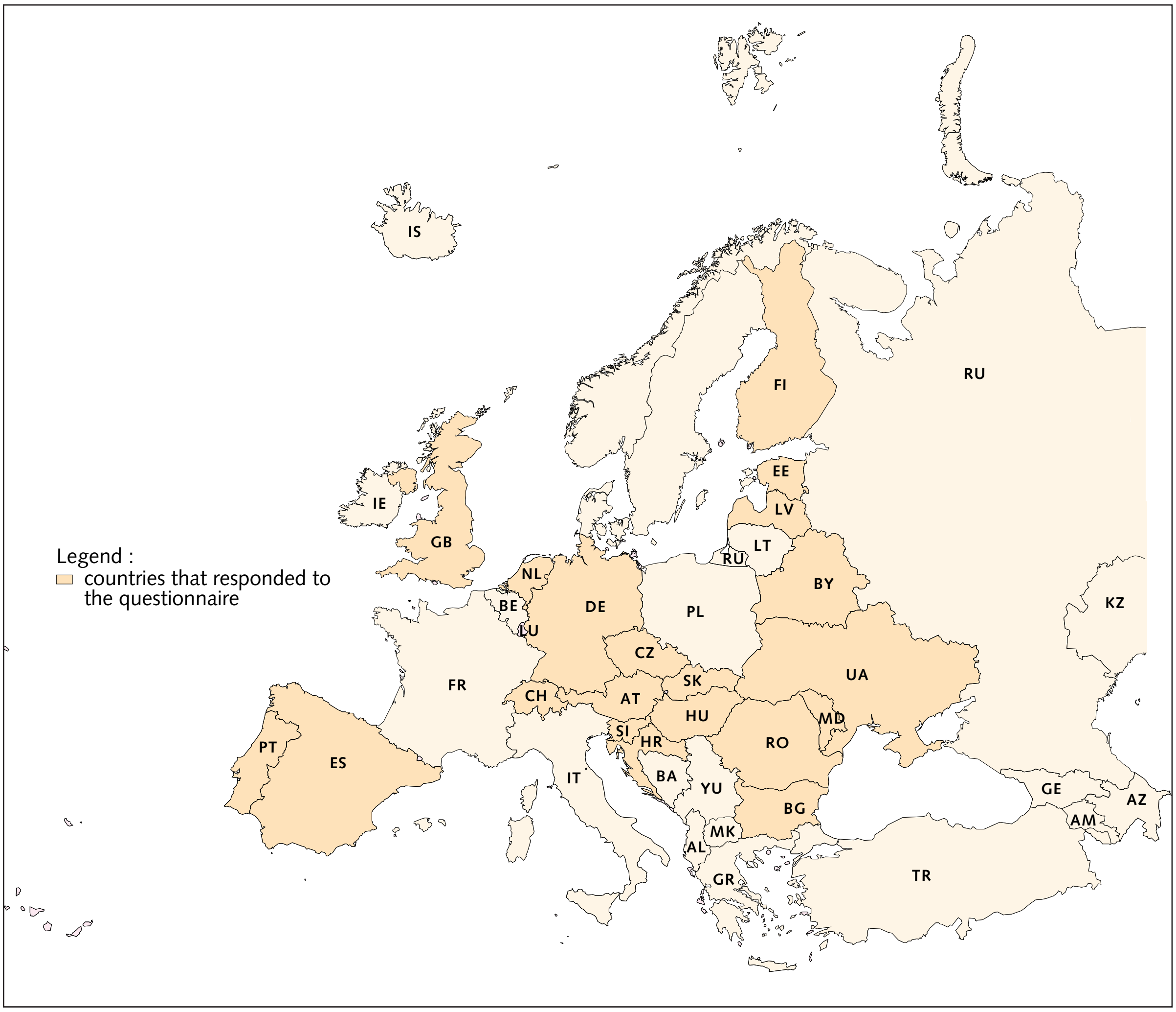
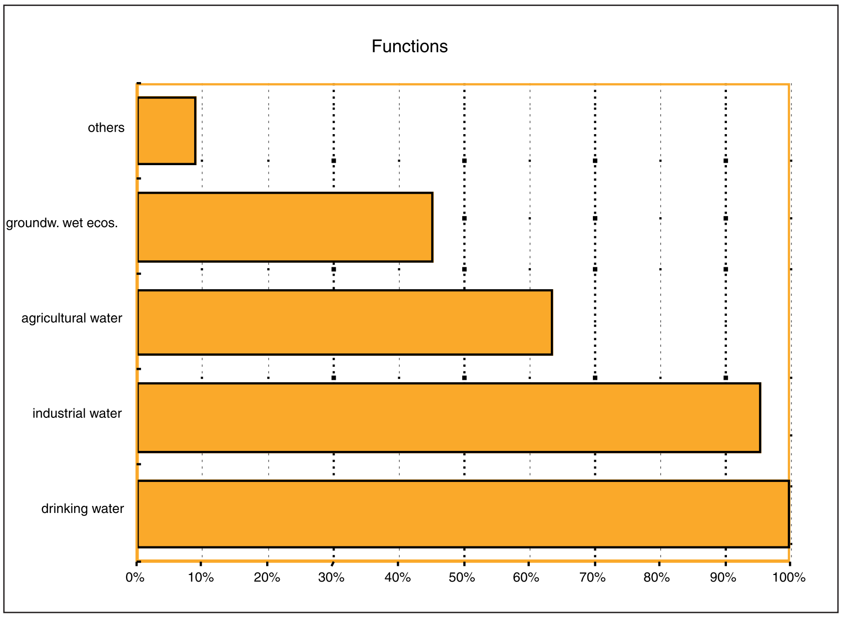



**Figure 4.2**
Score of functions of groundwater bodies as a percentage of the total numbers of countries that have replied to the questionnaire



## 4.3 Problems and threats

In the questionnaire, the countries have been asked to report problems and threats related to groundwater resources. The questionnaire makes a distinction between the following issues:

- management problems related to conflicting uses;
- desiccation (dehydration) of wet ecosystems;
- demand larger than recharge causing:
  - falling of groundwater levels
  - salinization
  - less recharge because of
  - deterioration of groundwater quality
- pollution (and the sources of pollution).

The results of these investigations are presented in figure 4.3.

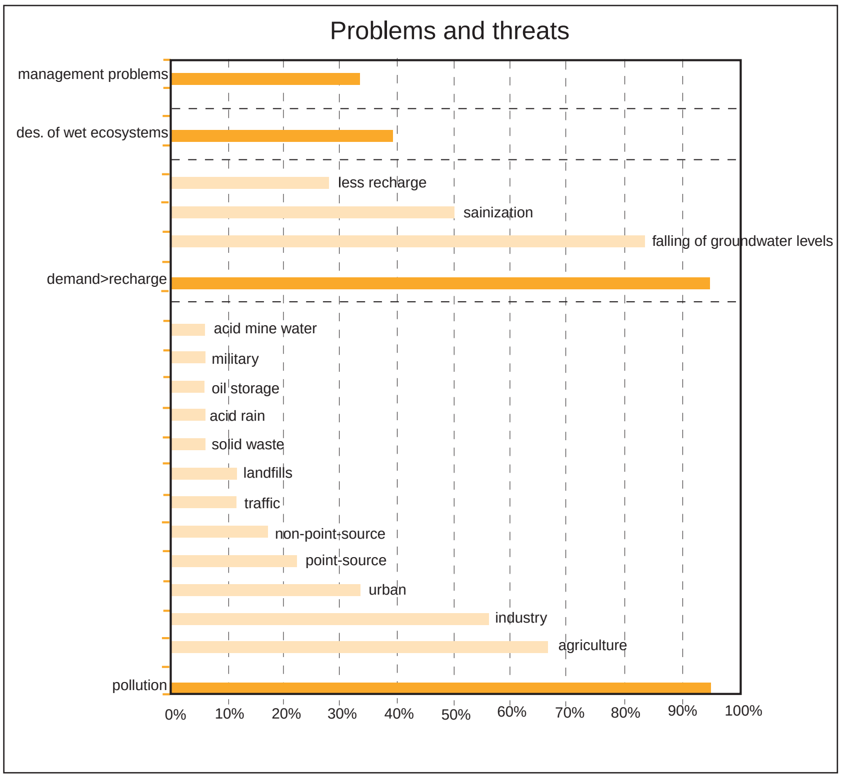



**Figure 4.3**
Score of problems and threats for groundwater bodies as a percentage of the total number of countries that have responded to the questionnaire.

## 4.4 Management objectives

The ECE-countries have been asked to describe their management objectives for the groundwater threats in relation to the function of the groundwater. From table 4.1 it becomes clear that they have more or less the same management objectives: "To protect the groundwater against pollution and over-exploitation in relation to a priority use of the water for drinking water supply". Some countries have a groundwater protection policy by implementation of protective areas, licenses and permits.

According to the answers of the questionnaire, there is a large difference between the countries in the implementation of groundwater management objectives. Some Eastern European countries have only a few poorly formulated management topics while other countries have a very specified integrated groundwater protection policy. It is striking that not a

**Table 4.1**
Overview of water management objectives of the different ECE-countries.

| | management objectives | quality | quantity | legislation |
|---|---|---|---|---|
| Austria | groundwaterprotection against | | exploitation>recharge | yes |
| Belarus | groundwaterprotection against | pollution | exhaustion | |
| Bulgaria | groundwaterprotection against | pollution | exhaustion | |
| Croatia | groundwaterprotection against | pollution | exhaustion | |
| Czech Republic | groundwaterprotection against | pollution | exploitation>recharge | |
| Estonia | agree upon | | extraction limits | |
| Finland | groundwaterprotection through | protecton zones | | yes, water courts |
| Hungary | groundwaterprotection against | pollution | exploitation>recharge | yes, to be improved |
| Lithuania | groundwaterobservation | pollution | exploitation>recharge | |
| The Netherlands | groundwaterprotection against | pollution | exhaustion | yes |
| Moldava | groundwaterprotection general | | | to be improved |
| Portugal | groundwaterprotection against | licences | | |
| Romania | groundwaterprotection against | pollution | exploitation>recharge | |
| Slovak Republic | groundwaterprotection against | pollution | | |
| Slovenia | groundwaterprotection against | pollution | exploitation>recharge | |
| Switzerland | groundwaterprotection through | | maintain present level | |
| The Ukraine | groundwaterprotection through | | permits | yes |
| United Kindom | groundwaterprotection against | pollution | exploitation>recharge | |

single country has described the development of indicators as a secondary objective, in order to tackle above mentioned problems.

### 4.5 Information needs

According to the questionnaire, the information needs, in order to evaluate the management objectives, vary enormously between the ECE-countries (see Annex 4). From table 4.2, it becomes clear that most countries need information about quality and/or quantity aspects of the groundwater.

**Table 4.2**
Overview of information needs to evaluate the management objectives of the different ECE-countries.

| | quality | quantity | others |
|---|---|---|---|
| Austria | | * | land use (cultivation) |
| Belarus | | | network |
| Bulgaria | * | * | trends, state |
| Croatia | | | |
| Czech Republic | * | * | demands,land-use,demographics, agriculture, industry, waste |
| Estonia | * | | |
| Finland | | | |
| Germany | | | |
| -Bavaria | * | * | |
| -Schleswig-Hol. | | * | |
| -Rhineland-Pal. | | | pumping tests, groundwater models |
| Hungary | * | * | state, demands, hydrometeorological |
| Lithuania | * | | |
| The Netherlands | * | * | trends, state, sources/pressures |
| Moldavia | * | * | state, future perspectives |
| Portugal | * | * | |
| Romania | * | * | trends, state, sources/pressures |
| Slovak Republic | * | * | sources |
| Slovenia | * | * | demands, discharge, geohydrological |
| Spain | * | * | land-use, demands and uses, state and trends |
| Switzerland | | | |
| The Ukraine | | | transboundary economic development |
| United Kingdom | | | |

It is clear that the kind of information needed is dependent on the management objectives, which are developed to protect the groundwater system. When better management objectives are formulated, the countries need more information to evaluate them. Countries with simple formulated management objectives for groundwater state that they only need information on the amount of groundwater extraction and/or recharge or information on the quality of the groundwater. Countries with a more integrated approach of groundwater protection need an enormous amount of information. This information varies from demands of water supply, quality of groundwater, geological, hydrological and hydrochemical conditions of the aquifer, and data on agriculture, to industry and households.

### 4.6 The use of indicators

From table 4.3 and Annex 3, it becomes clear that most of the countries do not have a set of indicators, or think that it is difficult to use indicators. If countries use indicators, these are mostly state indicators according to the PSIR-conceptual model proposed in this report. Most monitoring programs use the groundwater levels and chemical parameters: oxygen regimes (dissolved oxygen, BOD), nutrients (N, P), trace elements (heavy metals Cd, Pb, Hg and Cr) and volatile organic compounds (VOC).

**Table 4.3**
Overview of kind of indicators used by the different ECE-countries.

| | pressure quality | quantity | state quality | quantity | impact quality | quantity |
|---|---|---|---|---|---|---|
| Austria | | | | | | |
| Belarus | | * | * | * | | |
| Bulgaria | | * | * | * | | |
| Croatia | | | | | | |
| Czech Republic | | | | | | |
| Estonia | | | | | | |
| Germany | | | | | | |
| -Bavaria | | | | | | |
| -Schleswig-Hol. | | | | | | |
| -Rhineland-Pal. | | | * | * | | |
| Finland | | | * | * | | |
| Hungary | | * | * | * | | |
| Lithuania | | | * | | | |
| The Netherlands | * | * | * | * | * | |
| Moldavia | | | | | | |
| Portugal | | | | | | |
| Romania | | | | | | |
| Slovak Republic | | | | | | |
| Slovenia | | | | | | |
| Spain | | * | | * | | |
| Switzerland | | | | | | |
| The Ukraine | * | | * | | * | |
| United Kingdom | | | | | | |

A few countries mentioned that they use groundwater abstraction data as a pressure indicator. Pressure indicators for groundwater quality are hardly used. In a few countries, information on time and place of pollution events is used as pressure indicator.
Also the ratio of concentration of pollutants to a pre-industrial background concentration is used to indicate the state of the groundwater. In several cases, compliance of pollutant content with drinking water standards is used as impact indicator.

# 5. Problem oriented approach for three major reported examples

This chapter presents some examples of the selection of indicators which could be used in groundwater monitoring and assessment projects. The stepwise selection of indicators proposed in chapter 3 is used. From the questionnaire it becomes clear that drinking water production is the most important function of groundwater, followed by industrial water production and agricultural water production. A shallow groundwater table for wet ecosystems is declared by half of the countries as a function of groundwater systems. Major problems are pollution caused by agriculture and industry, and the falling of the groundwater table caused by the demand exceeds the recharge.

The first step in this stepwise approach is the specification of information needs. In the proposed approach, issues and functions are first determined. Then, a function-issue table can be constructed, from which more specific problems evolve. As part of this step-wise approach, a list of available PSIR-indicators is made and the stage in the management life cycle is determined. To further specify the information needs, answers to the questions as stated in paragraph 3.6 are gathered. If the approach is properly followed, it results in selection criterion which enable water managers to choose or develop the most useful and cost-effective indicators for tailor-made monitoring and assessment programs.

## 5.1 Drinking water production and the pollution of groundwater by agriculture

Excess fertilisation and manure spreading in agriculture is the main source of excess nutrient loads in groundwater used for drinking water production. This example will be worked out for a country with a large-scale groundwater system from which, at a number of locations, groundwater is extracted for drinking water production. Around the drinking water production wells there are a few monitoring wells. The aquifer consists of sandy material and is not protected by a clay layer.

The groundwater withdrawal shows a slow, continuous increase of the nitrate concentration. It seems that the nitrate concentration will reach excessive levels, so there will be a potential risk for human health. The government of this country decides that the problem has to be solved and the groundwater has to be saved as a source for drinking water production for future generations. The only way is to reduce nutrient loads, but the government is uncertain about acceptable concentration levels. Policy makers demand information about compliance with drinking water standards.

### 5.1.1 Specification of monitoring objectives and information needs

Once the identification of issues has been made and the problem is described, the next step is the translation into monitoring objectives. The major monitoring objective is to show the trend in the nitrate concentration of the groundwater and to predict the nitrate concentration of the groundwater in the future.

### 5.1.2 Available PSIR-indicators

**Pressure**

Agricultural activities, particularly intensive cattle breeding, can cause a quality change of the groundwater. The Dutch government has developed specific quality standards for groundwater to protect human health (NMP, 1989). The problem with these standards is that they are not formulated at the farm level. The farm levels for manure would be ideal pressure indicators for excess nutrient loads. These farm levels have to be calculated on a national, regional or local scale depending on local characteristics or the heterogeneity of the soil and groundwater. The textbox 5.1 contains an example of the translation of the quality standards for nitrate in groundwater to farm level.

**Box 5.1**
Farm levels of nitrate leaching as a pressure indicator for excess nutrient loads.

A major problem caused by excess nutrient load of the soil is the rising of nitrate concentrations in groundwater. A too high nitrate concentration in drinking water is dangerous for the human health. Bags and Biewinga (1995) performed a study to translate these groundwater quality standards to standards at farm level. They investigated the relationship between the nitrogen input at surface level and the leaching of nitrogen. Their conclusion is that this relationship is mainly dependent on the groundwater level, the type of soil and the characteristics of farming (intensity, the level of N-fertilisation, proportion of grassland area, manure imports and exports, and the grassland use).

Based on the standard for drinking water (50 mg of nitrate per litre) a leaching standard is determined (34 kg of N per ha). Thus, if 34 kg N/ha/y is estimated to be equivalent to 50 mg/l for given recharge conditions, and the actual combination of crop, soil and water table conditions and fertiliser or manure application suggests leaching of 60 kg N/ha/y, then you have an indicator of pressure on the groundwater system. One can do the same for other sources of nitrate, such as sewer systems or septic tanks.

At a representative Dutch dairy farm producing 12.000 kg of milk per ha in the most vulnerable situation (dry sand with a groundwater level below the root zone), there is an excess nitrogen leaching of 128 kg N per ha.

**State**

An overview of state indicators for excess nutrient loads of the soil is given in table 5.1. State indicators can be used in early warning systems to predict a future state. Dependent on the type of soil, the state indicator for the groundwater can be selected. In the example of a sandy aquifer, nitrate is the only state indicator for excess nutrient loads.

**Table 5.1**
State indicators for excess nutrient loads to groundwater dependent on the type of soil
(Baggelaar and Van Beek, 1995).

| State/indicator | Type of soil | Specification |
|---|---|---|
| Nitrate | Sand | Deep groundwater table |
| Ammonium | Clay, peat | Infiltration area |
| Phosphate | Peat-moor | No mineralisation |
| | Sand | Not calcareous, low clay content, shallow groundwater |
| table | | |
| Potassium | Sand | Low clay content, no freshwater intrusion |

The possibilities are:
- groundwater nitrate concentration in the area around the pumping well;
- nitrate concentration of the extracted groundwater.

**Impact**

For the drinking water supply, impact indicators often have a clear connection with national drinking water standards. Possible impact indicators for excess nutrient loads are:
- the amount of raw groundwater which needs additional treatment or dilution, before it can be distributed to the public;
- the costs of additional treatment;
- the closing of drinking water sources, due to poor groundwater quality.

**Response**

Possible response indicators for excess nutrient loads to groundwater are:
- the percentage of the population that uses bottled water as drinking water;
- the percentage of the population that eats biological food or that is vegetarian;
- the total amount of liquid manure which is processed in a way that is not harmful to the environment;
- the extent (ha) of groundwater protection areas with regulations for reduced manuring and fertiliser applications;
- the extent (ha) of areas with controlled cultivation of crops.

### 5.1.3 Policy life-cycle

The increase in nitrate concentration has been observed for a considerable time and the policy makers made a start with the preparation of control measures, and so the problem is in the policy-formulation stage (Winsemius, 1986).
Insight into the most cost-effective way to realise the water management goals is required. Persistence in efforts to tackle the problem and putting forward many solutions as possible are important.

### 5.1.4 Answers to questions

Information is needed about the flow of groundwater and the geological layers, through which it flows. At the same time information is needed about the density and location of monitoring wells.

### 5.1.5 Selection criteria

The criteria for the selection of indicators are:
- the possibility to evaluate and to make prognoses about management measures;
- the possibility to make cost/profit analyses;
- the possibility to show trends over the term;
- the possibility to give insight into the state of the groundwater system in terms of management objectives;
- the simplicity/clarity of use.

### 5.1.6 Final selection of indicators

Based on the criterion mentioned before, the proposal is to combine a groundwater sampling program with nitrogen balances at farm level. This should be cost-effective and give enough information to develop a proper management program for the groundwater system.
For the detection of trends and the prediction of the future development of the nitrate concentration, sampling of the monitoring wells for nitrate once every four-years (as state indicator) is sufficient. This should be combined with a forecast of the leaching of nitrate (as a pressure indicator).

If a significant trend is discovered and the future development of the nitrate concentration can be predicted, the amount of groundwater that needs additional treatment and the cost of this treatment (impact indicator) can be calculated.

## 5.2 Drinking water production and pollution of groundwater by industry

In many cases industrial activities pollute the environment. In contrast to agriculture, the pollution by industry mostly comes from point sources. It is possible to distinguish organic- or inorganic industrial waste. Organic-substances are mostly divided into groups with the same chemical behaviour, like volatile organic compounds (VOC), poly aromatic hydrocarbons (PAH's), dioxins or solvents like BETX (Benzene, Ethylene, Toluene and Xylene). The inorganic species are for instance heavy metals, such as (the most notorious are cadmium (Cd), zinc (Zn), cobalt (Co) lead (Pb) and nickel (Ni)) and there are acidifying compounds like SOx and NOx. Acidifying waste gasses like SOx and NOx have significantly decreased the pH of rainwater. This reduced the buffering capacity of soils and rocks, causing an increase in acidity of shallow groundwater, especially in areas deficient in carbonate minerals. Increasing acidity (decrease in pH) may give rise to undesirable increases in dissolved metals.

### 5.2.1 Information needs and monitoring objectives

Drinking water production is threatened by the emission of SOx and NOx from industrial sources. For several years, the groundwater shows a slight decrease in pH. A few months ago an abrupt decrease in pH was discovered, together with an increase in dissolved aluminium concentration. High aluminium concentrations can be dangerous for the human health. It can for instance cause Alzheimers disease. A policy has to be developed to protect human health and groundwater quality. Indicators are needed to measure the progress towards the management goals.

### 5.2.2 Available PSIR-indicators

Pressure indicators
Pressure indicators for acidification of groundwater are:
- emission of the acidifying compounds SOx and NOx by burning of fossil fuels;
- atmospheric deposition of the acidifying compounds SOx and NOx;
- vulnerability of the soil for acidification.

**State indicators**

The influx of acidifying substances into the soil and groundwater will be neutralised by a series of buffer-reactions, to prevent the groundwater from changing pH:

- 6.2 < pH < 8.0: buffering by calcium carbonate;
- 4.2 < pH < 6.2: buffering by adsorption to the exchange-complex;
- pH < 5: buffering by solution of aluminium hydroxide.

In calcareous sandy soil, the acid will be neutralised by the calcium carbonate-buffer, in clay soils by the exchange-buffer and in non carbonate sandy soils by the aluminium-buffer. The pH of the groundwater is not a good state indicator for acidification. A drop in pH is limited because of the reaction of the supplied acid with the buffering constituents in the soil. Good state indicators for acidification are the concentration of weathering products of the buffering reactions (hardness/bicarbonate and aluminium) and substances contributing to acidification (sulphur and nitrogen compounds).

When the pH of the groundwater becomes less than 5 (buffering by aluminium hydroxide), there will be an increase in dissolved metals, including harmful heavy metals like lead, zinc and cadmium. By weathering of heavy metals containing minerals those substances will dissolve. Their concentrations in groundwater are also state indicators for acidification.

**Impact indicators**

An impact indicator is the state indicator that considers the function attached to the groundwater system. For drinking water supply, the impact indicators often have a clear connection with the national drinking-water standards. When the primary function of the groundwater is to provide drinking water supply, possible impact indicators for acidification are:

- the amount of raw groundwater which needs additional treatment or dilution before it can be distributed to the public;
- the costs of additional treatment;
- the number of water sources closed due to poor groundwater quality.

**Response indicators**

Possible response indicators for acidification of groundwater by emission of SOx and NOx from industrial sources are:

- the amount of fossil fuels with a low S and N content used;
- the use of gas cleaning installation;
- closing of industries using fossil fuels.

### 5.2.3 Policy life-cycle

As described above, a slight decrease of the pH of the groundwater was observed for some time. Recently, a rapid decrease of the pH and an increase of the aluminium concentration were observed. The latter is the actual groundwater quality problem, which is admitted by waterworks and public, but is not yet admitted by politicians; i.e. this is still the admission stage of the management life-cycle. Suitable indicators must be sensitive to stress, show a quick response and show trends over a long time. Short-term solutions are more important than cost-effective problem solving. In the mean time, the problem is sufficiently quantified (by indicators!) and there will be enough understanding of the cause/effect-chain to put forward more cost-effective measures.

### 5.2.4 Answers to questions

The groundwater system in this example is large in scale, but only a few production wells show a high aluminium concentration. So, the problem occurs at a scale which is small in comparison with the total groundwater body. This is a consequence of the special variation of the buffer capacity of the soil. Acidic groundwater, which flows through the non-carbonate parts of the aquifer, shows an increase in aluminium concentration. It would be very useful to know the location of the most vulnerable parts of the aquifer.

### 5.2.5 Selection criteria

The problem with the groundwater was discovered recently. Local water managers need tools to assess the impact of the rising aluminium concentration of the groundwater, if this is used for drinking water supply. They need data about the current spatial variation of the aluminium load of the groundwater and the future development of the aluminium concentration. An assessment of the risk of aluminium in drinking water for human health has to be made.

An indicator in this example has to assess the risk of groundwater acidification to human health. The selection criteria for the final selection of indicators are that indicators have to:
- give insight into the spatial vulnerability of the aquifer for acidification, particularly the vulnerability for increase in aluminium concentration;
- give an overview of the emission and deposition of acidifying compounds;
- assess the effect of aluminium in drinking water on human health.

### 5.2.6 Final selection of indicators

Based on the mentioned criteria the following indicators are proposed:
- the annual deposition of SOx and NOx (historical and actual);
- the buffer capacity of the soil (lime and clay content);
- the aluminium concentration in drinking water can be compared to the standard.

If an inventory of those three indicators has been made, it is possible to develop a management strategy to protect human health. Perhaps it is sufficient to remove the drinking water production wells to less vulnerable locations in the aquifer. If this is not possible, a policy has to be developed for reducing the emission of SOx and NOx by industry.

## 5.3 Falling groundwater levels

### 5.3.1 Problem description

Changes in groundwater levels can have disastrous settlement effects and enormous effects on wet ecosystems. Land subsidence can cause severe damage to buildings and infrastructure, such as roads and railways. Wet ecosystems or wetlands are very important nature reserves and are mostly located in low areas such as river flood-plains and river deltas. These systems depend on a shallow depth of the groundwater table and are very sensitive to small changes in groundwater level and groundwater quality.

The problem-oriented approach can be used to describe indicators for a groundwater system in which the function is the wet ecosystem and the threat is desiccation.

### 5.3.2 Available PSIR-indicators

**Pressure**

Useful pressure indicators for falling groundwater levels are:
- the amount of groundwater withdrawn for drinking water supply;
- the amount of groundwater withdrawn for industrial water supply;
- the amount of groundwater withdrawn for agricultural water supply;
- the depth of land drainage;
- regulation of surface water;
- area of land use for different functions;
- the amount of water efficient industries.

**State**

State indicators for falling groundwater levels are:
- the average groundwater table (highest, lowest, in summer or in spring);
- the fluctuation of the groundwater table;
- the quality of the groundwater (concentration of nutrients and contaminants from industrial activities);
- the area where groundwater is affected by Saline intrusion (in coastal areas mostly).

**Impact**

Impact indicators include shallow wells drying up due to falling groundwater levels, the need to deepen wells, increasing pumping costs, increased maintenance costs due to greater pumping lifts, subsidence in unconsolidated aquifers and looking for surface water as alternative source.

Wet ecosystems can be monitored using plant species or animal species as indicators (Jalink, 1991, Aggenbach et al., 1996). Changes in the ecosystem, especially changes in the water regime, result in the vanishing or appearing of plant species. When the typical reaction of a plant species to changes in the groundwater regime is known, the plant species can be used as an indicator for changes in groundwater table. This is the principle behind the hydro-ecological system-analysis, which is a very useful tool for groundwater monitoring and assessment. The presence and/or change in vegetation can be used as an impact indicator.

**Response**

Response indicators for falling groundwater levels are:
- control groundwater abstraction;
- extent (ha) of groundwater protection zones;
- annual budget spent on groundwater resource protection.

### 5.3.3 Policy life-cycle

The falling of groundwater levels has been observed for some time, and the policy makers have made a start with the preparation of measures, such that the problem is in the policy-formulation stage (Winsemius, 1986). Insight into the most cost-effective way to realise the watermanagent goals is required. Persistence in efforts to tackle the problem and putting forward as many solutions as possible is important.

#### 5.3.4 Answers to questions

The general objectives of groundwater quantity monitoring will be the acquisition of information about the groundwater levels (hydraulic pressures), the direction and quantity of groundwater flow (including recharge and discharge areas) and groundwater balances. Information will be needed from recharge towards discharge of the groundwater system. The needed information have to be acquired from different sources, not only from a groundwater quantity network system (Uil et al., 1999).

If wet ecosystems are threatened, there is much information needed about the hydro-ecological system on a local scale. Hydrological processes should be determined, and their influence on flora habitats should be investigated. The presence of plant species at a certain location is dependent on (1): the non-biological environmental circumstances in the ecosystem and (2): the site-conditions of the species. When there is a clear vertical stratification in the soil, the rooting zone of vegetation becomes an important aspect for monitoring with indicator species.

#### 5.3.5 Selection criteria

The criterion for the selection of indicators are:
- the possibility to evaluate and to make prognoses of the management measures;
- the data from the quantified variables (1 up to 4) can be directly measured and should be included in a monitoring network or be obtained easily otherwise. The central storage of all the relevant data in an easy accessible database is a must for an efficient evaluation of the groundwater situation. Possibility to make cost/profit analyses;
- to give insight into the state of the groundwater system in terms of management objectives;
- easy to understand.

#### 5.3.6 Final selection of indicators

Possible variables of groundwater quantity are primarily (Uil et al., 1998):
- the water level measurements within an observation well;
- the discharge of abstractions and springs;
- the induced recharge (disposal of effluent, storage of drinking water etc.);
- the interaction with the surface water system (levels and flows).

The data from the quantified variables (1 up to 4) can be measured directly and should be included in a monitoring network or be obtained easily otherwise. The central storage of all the relevant data in an easy accessible database is a must for an efficient evaluation of the groundwater situation.

Then, for balancing recharge, storage and discharge of the groundwater resources, data will be needed on:
- climatological conditions (e.g. precipitation, evapo-transpiration);
- soil moisture;
- the return flow from irrigation;
- the possible interaction between sewerage systems and groundwater.

The use of plant species as indicators for changes in wet ecosystems has clear benefits in comparison with hydrological or hydrochemical monitoring networks, for which tubes have to be placed. The vegetation can be used as a naturally present, very high density monitoring network (Jalink, 1993). Because the vegetation is visible, it is easy and cheap to monitor. It is also possible to use a hydrological or hydrochemical network combined with a vegetation-monitoring network. Results of both networks can be compared, or the results of the vegetation-monitoring network can be used to make a decision for the best locations of a hydrological or hydrochemical network.

# 6. Key points

- Monitoring networks should be designed to enhance their capacity to tailor monitoring objectives to the apparent information needs of policy makers and water management bodies and also to analyse the resulting information in an integrated way. The use of indicators and indices will help the integrated assessment as well as the specification of information needs prior to the set up of monitoring objectives.

- Constructing indicators require a balances approach between the information needs of decision making and the costs and constraints to obtain the appropriate data. In the initial development, the definition and understanding of concerns and needs of the population and the river basin groundwater management precedes the definition of indicators.

- Problems and threats in groundwater management that are encountered in the countries that have replied to the UN/ECE Groundwater Core Group questionnaire include almost equally both quality and quantity problems. The reported management objectives are primarily focused on the protection of groundwater resources against pollution and secondly against over-exploitation.

- The type of information that is needed in order to evaluate the management objectives varies widely. This confirms the need of a problem-oriented approach; countries with more integrated approach of groundwater protection need a huge amount of information, which can vary from demands of water supply, groundwater quality, geology, hydrogeological and hydrochemical conditions of the aquifer to data on agriculture, industry and households.

- The absence of a stepwise approach to implement indicators as part of monitoring forms a major barrier to implement indicators in water management. This, combined with the sparse methodologies to specify information needs also hampers the use of indicators.

- Frameworks and conceptual models as mentioned in this report will help in the tailor-made selection and the development of indicators such as function oriented or policy oriented development of indicators. Moreover, although problems and information needs might differ between riparian countries, the use of this approach and these conceptual models will facilitate the comparison of the resulting collected information.

- It is recommended to start the implementation of the use of indicators in concordance with on-going optimisation efforts of monitoring systems, since the presented approach closely follows the methodology to specify information needs as described in the UN/ECE guidelines for monitoring of transboundary groundwaters.

- Indicators are a promising tool in water management and the implementation of indicators should lead to a comprehensive system that is not only understandable by experts, but by the general public as well. This implementation has also to include an educational phase in which water managers can become at ease and acquainted with the prospects for the use of indicators in water management.

- The examples of indicator use as described in this report will help when setting up the use of tailor-made indicators per transboundary water management region, since they include both quality and quantity problems as encountered in the ECE countries that responded to the questionnaire.

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# Annex I
# Possible indicators of rapid environmental change in groundwater systems developed in Great Britain

| Priority | Issue/Problem | Primary indicators | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Water Level | HCO3 | DO | pH | DOC | NO3 | Cl | SO4 |
| * | Desiccation | * | | | | | | | |
| * | Total groundwater reserves | | | | | | | | |
| * | Acid neutralisation | * | | * | | | | | |
| * | Groundwater salinity | | | | | | * | | |
| * | Agricultural impact | | | | * | * | | | |
| * | Urban industrial impact | | * | | | * | | * | |
| | Radioactive contamination | | | | | | | | |
| | Aquifer redox status | | * | | | * | | | |
| | Land use/forestry change | | | | | | * | * | |
| | Depletion of palaeowater | | | | | | | | |
| | Changing recharge and Climatic infuence | | | | | | | | |
| | Mining impact | | | | * | | | | * |

| Priority | Issue/Problem | Secondary indicators | | | |
|---|---|---|---|---|---|
| | | | Saturated zone | Unsaturated zone | Frequency measurement (yrs) |
| * | Desiccation | Spring discharche | * | | 0.25 |
| * | Total groundwater reserves | Indices of water quality storage change | * | | 5 |
| * | Acid neutralisation | Al, Ca | * | * | 0.5 |
| * | Groundwater salinity | Mg/Cl, Br, $\delta^{18}O$, $\delta^{2}H$ (TDS, SEC) | * | * | 5.5 |
| * | Agricultural impact | K, Na, $PO_4$, pesticides | * | * | 0.5 |
| * | Urban industrial impact | B, $PO_4$, solvents, metals etc. (CTC) | * | | 0.5 |
| | Radioactive contamination | $^{3}H$, $^{36}Cl$, $^{85}KR$ | * | * | 2 |
| | Aquifer redox status | Eh, $Fe^{2+}$, HS | * | | 0.5 |
| | Land use/forestry change | | * | * | 2 |
| | Depletion of palaeowater | δ18O, $\delta^{2}H$, $^{14}C$ | * | | 2 |
| | Changing recharge and Climatic infuence | $\delta^{18}O$, $\delta^{2}H$ | | | |
| | Mining impact | Metals | | | |

# Annex II
# Environmental indicators of water quality in the United States

*Comparison of National Goals, Water subgoals, Indicators and Milestones for groundwa-ter (U.S. EPA Office of Water, 1995)*

| National Goal | Water Subgoal | Indicator | 2005 Milestone Statement |
|---|---|---|---|
| Save drinking water<br><br>Every public water system will consistently provide water that is safe to drink | Conserve and Enhance Human Health | Source water protection | 50 percent of community water systems (30,000) will have drinking water protection for both surface and groundwater source waters. |
| | | Cases form waterborne disease out-break attributable to public systems | |
| | | Blood lead levels in children | |
| | | Violations of drinking water standards | 95 % of the 243 million people served by drinking water systems will provide water that meets health requirements throughout the year |
| Clean Waters<br><br>Our waters will support human health and uses, such as swimming, fishing, drinking water supply, agriculture and industry. Our waters also will support ecosystem health communities of plants, fish, insects, and other animals that depend on the water. We will conserve our remaining wetlands and restore others to health | Conserve and Enhance Aquatic Ecosystems | Species at risk | Half of the aquatic species currently designated as threatened or endangered will have stable or increasing populations. |
| | | Biological integrity of the water | 65 % of rivers and streams and 85 % of estuaries will sup-port healthy and assessed sustainable biological communities |
| | | Wetland acreage | There will be no overall loss of wetlands |
| | | Habitat quality | |
| | | Riparian vegetation | |
| | Support Uses Designated by States | Waters meeting drinking water supply designated use | 90 % of the nation's rivers, streams, lakes, and reservoirs designated as drinking water supplies will provide water that is safe to use as a sour-ce for drinking water |
| | | Waters meeting aquatic life designated use | 85 to 90 % of the Nation's surface waters will support aquatic life |
| | Conserve or Improve Ambient Condition | Selected groundwater quality constituents | 50 percent of the wells monitored for groundwater quality will fully support each state's intended uses of the water, such as for drinking water , agricultural irrigation, or industrial processing |
| | Reduce or Prevent Pollutant Loading and Other Stresses | Non point source loading to surface- and groundwater | There will a 20 percent reduction in sediment eroded from agricultural cropland |
| | | Point source loading to surface- and groundwater | Discharge of pollutants of concern to surface waters will be reduced by 1.668 million pounds from CSOs, by 2,9 millions pounds from sewa-ge treatment plants, and by 700 million pounds from industrial sources. |

# Annex III
# Common selection criteria with definitions (indicators Branch, 1994)

**USEFULNESS TO DECISIONMAKERS**

**Understandable:**
The indicator must be simple and clear; its significance should be fairly obvious and easily understood by those non-specialists intended to make use of them, particularly in the context of the issue to which it is related.

**Relevant:**
The indicator should provide information that can be used, i.e. relevant to the needs of the potential users. The indicator should be relevant to stated goals and objectives as well as to policies or issues of concern.

**Target/threshold:**
Ideally, the indicator should have a target or threshold for comparison, in order that users are able to assess the significance of the values associated with it.

**Potential for comparison:**
The indicator should be presented, so that comparisons may be made with other regions and nations.

**ISSUE RELEVANCE**

**Scientific validity:**
The indicator should be technically sound, consistent with scientific understanding of the system or elements being described, its attributed significance and defensible. There should be general consensus among experts about the validity of indicators.

**Representative:**
The information that an indicator conveys about a phenomenon should be representative for the condition of the whole.

**Responsive to change:**
The indicator should show changes or trends in the environment or in an environment related human activity, ideally within a fairly short time-frame.

**Predictive:**
The indicator should provide an early warning of future trends that have implications for human health, the economy and the ecosystems.

## DATA RELIABILITY

**Cost-effectiveness:**
The indicator should be administratively feasible with regard to the costs of obtaining and using the data.

**Geographic coverage:**
The indicator should be either national in scope or applicable to regional environmental issues with national significance.

**Data adequacy:**
The data should be as accurate as possible and of good quality. The security of data monitoring programs should be reasonable stable to ensure future comparable data.

**Data availability:**
The data required to support the indicator should be available or it should be reasonable to assume that the data could be acquired in a timely manner. The indicators should be supported by sufficient data (more than one time period) to show trends over time.

# Annex IV
# Questionnaire Problem-oriented approach and the use of indicators

### 1 Which functions and uses can be distinguished in the groundwater system

| | Drinking water supply | Industrial water supply | Agricultural water supply | Shallow groundwater for wet eco-systems | others |
|---|---|---|---|---|---|
| Austria | * | (*) | * | * | |
| Belarus | * | * | * | | |
| Bulgaria | * | * | * | * | *1) |
| Croatia | * | * | | | |
| Czech republic | * | * | * | | |
| Estonia | * | * | | | |
| Finland | * | * | * | * | |
| Germany | | | | | |
| -Bavaria | * | * | * | * | *1) |
| -Rhineland- Palatinate | * | * | | | |
| -Schleswig-Holstein | | | | | |
| Hungary | * | * | * | * | |
| Lithuania | * | * | | | |
| The Netherlands | * | * | * | * | |
| Moldavia | * | * | * | * | |
| Portugal | * | * | * | | |
| Romania | * | * | | | |
| Slovak Republic | * | * | * | * | |
| Slovenia | * | * | * | * | |
| Spain | * | * | * | | |
| Switzerland | * | * | | | |
| The Ukraine | * | * | | | |
| United Kingdom | * | * | * | * | |

1) thermal spa, geothermal energy and production of some substances (e.g. iodine)

### 2 Which problems may occur in the groundwater system

| | Pollution | Sources |
|---|---|---|
| Austria | * | |
| Belarus | * | Agriculture, industry |
| Bulgaria | * | Point and non-point sources of pollution |
| Croatia | * | |
| Czech republic | * | Agriculture, industry, solid waste, urban |
| Estonia | | |
| Finland | * | Acid rain, contaminated soils (fertilisers etc.) |
| Germany | | |
| -Bavaria | | |
| -Schleswig-Holstein | * | Agriculture |
| -Rhineland-Palatinate | | |
| Hungary | * | Agriculture, industry, urban |
| Lithuania | * | Agriculture, point sources: landfills, oil storage |
| The Netherlands | * | Agriculture, industry, urban |
| Moldavia | | |
| Portugal | * | Agriculture |
| Romania | * | Agriculture, industry, urban |
| Slovak Republic | * | Agriculture, industry, urban |
| Slovenia | * | Agriculture, industry landfills, traffic |
| Spain | * | Agriculture |
| Switzerland | * | |
| The Ukraine | * | Agriculture, industry, military |
| United Kingdom | * | Agriculture, industry, urban |

| | Demand larger than recharge | Causing |
|---|---|---|
| Austria | * | Falling of groundwater levels, salinization |
| Belarus | * | Less recharge because of withdrawal |
| Bulgaria | * | Falling of groundwater levels due to dams construction and riverbed correction, salinzation |
| Croatia | * | Falling of groundwater levels |
| Czech republic | * | Falling of groundwater levels |
| Estonia | | |
| Finland | * | Falling of groundwater levels, salinization |
| Germany | | |
| - Bavaria | * | Falling of groundwater levels |
| - Schleswig-Holstein | | |
| - Rhineland-Palatinate | * | |
| Hungary | * | Falling of groundwater levels, less recharge because of dry climatic character |
| Lithuania | * | Falling of groundwater levels, salinization |
| The Netherlands | * | Falling of groundwater levels, less recharge because of drainage of agricultural soils |
| Moldavia | * | Falling of groundwater levels, salinization, less recharge |
| Portugal | * | Falling of groundwater levels, salinization |
| Romania | * | Falling of groundwater levels, salinization |
| Slovak Republic | * | salinization |
| Slovenia | * | Falling of groundwater levels, less recharge because of falling of water levels in the rivers due to the river bed erosion |
| Spain | * | Falling of groundwater levels, salinization, detoration of groundwater quality because of overexploitation |
| Switzerland | * | Falling of groundwater levels |
| The Ukraine | * | Falling of groundwater levels, salinization |
| United Kingdom | * | Falling of groundwater levels |

| | Desiccation of wet ecosystems | | Desiccation of wet ecosystems |
|---|---|---|---|
| Austria | | The Netherlands | * |
| Belarus | | Moldavia | * |
| Bulgaria | | Portugal | |
| Croatia | | Romania | |
| Czech republic | | Slovak Republic | * |
| Estonia | | Slovenia | * |
| Finland | | Switzerland | |
| Germany | | Spain | |
| -Bavaria | | | |
| -Schleswig-Holstein | | | |
| -Rhineland-Palatinate | * | | * |
| Hungary | * | The Ukraine | |
| Lithuania | * | United Kingdom | * |

| | Management problems related to conflicting uses between |
|---|---|
| Austria | |
| Belarus | |
| Bulgaria | Drinking water supply, irrigation, industrial water supply |
| Croatia | |
| Czech republic | Recharge area, protection against pollution, agriculture |
| Estonia | |
| Finland | |
| Germany | |
| -Bavaria | |
| -Schleswig-Holstein | |
| -Rhineland-Palatinate | |
| Hungary | Environment, agriculture, water use |
| Lithuania | |
| The Netherlands | Water supply and shallow groundwater needed for wet ecosystems |
| Moldavia | |
| Portugal | |
| Romania | |
| Slovak Republic | |
| Slovenia | Drinking water supply and agriculture |
| Spain | |
| Switzerland | |
| The Ukraine | On local level between mining industries and local population |
| United Kingdom | |

## 3 The management objectives for the described groundwater system

| | Management objectives |
|---|---|
| Austria | No exploitation of groundwater resources going beyond limits set by natural recharge<br>Strict linkage of the intensity of agriculture (the main consumer of water abstraction for irrigation) to the possibility set by natural recharge of groundwater resources. |
| Belarus | Groundwater protection from pollution and exhaustion |
| Bulgaria | Integrated quality and quantity management of groundwater in order to be used as a reliable source for drinking water supply, for other uses and to protect wet ecosystems |
| Croatia | An insurance necessary for water quantity of a good quality and water protection |
| Czech republic | To keep the acceptable water quality and not overabstract the groundwater resources |
| Estonia | To agree upon extraction limits |
| Finland | The groundwater areas are classified in three different categories. For the most important aquifers there are protection zones confirmed by water courts. |
| Germany | |
| -Bavaria | 1) economical thermal spa, 2) double wells assumption for geothermal use. Both parts for lesser influence on the natural groundwater system |
| -Schleswig-Holstein | Drinking water production |
| -Rhineland-Palatinate | Environmentally sound groundwater management |
| Hungary | Quantitative protection of groundwater resources; determination of exploitable amount of groundwater<br>Protection of groundwater resources against human induced pollution; protective zones and active protection<br>Improvement of the legislative background |
| Lithuania | Observation of groundwater quality and water levels by a national monitoring network |
| The Netherlands | To solve environmental problems, the Dutch govern-ment has developed a set of environmental issues (eutrophication, acidification, dispersion and desiccation, for each of these issues the government has developed a policy to guarantee sustainability of the groundwater resources |
| Moldavia | Improvement of legislation frameworks in domain of water use<br>Improvement of the management system, of the supervision (monitoring) system and protection of groundwater system |
| Portugal | Licence every water point, promote studies and define monitoring network |
| Romania | Avoid over-exploitation of groundwater and protect groundwater resources to pollution |
| Slovak Republic | Predominantly use for drinking water supply, prevent protect against water quality decline |
| Slovenia | Optimal use of groundwater and protection of water source<br>Active protection of the groundwater<br>Priority use of the groundwater for drinking water supply<br>Elimination of use of good quality groundwater sources for agriculture and industry<br>To avoid overexploitation of groundwater sources |
| Spain | Protection of water resources (quantity and quality)<br>Allocation of resources for different demands |
| Switzerland | To maintain the groundwater level to its present level |
| The Ukraine | Justification of groundwater permits, development of legislative system for transboundary groundwater issues |
| United Kingdom | Varies regionally, too complex to answer |

## 4 Information needed in order to evaluate the management objectives

| | Information needed |
|---|---|
| Austria | - reliable information about development of groundwater tables<br>- data about the cultivation of crops (what kind of crops, areas) |
| Belarus | - network |
| Bulgaria | - information concerning quantitative and qualitative aspects of groundwater for the assessment of their present condition and trend identification |
| Croatia | |
| Czech Republic | - detailed data on groundwater demand<br>- land use maps and data<br>- urban and demographic data<br>- data on agriculture, particularly fertilisers and pesticides<br>- data on industry, particularly chemistry, etc.<br>- main waste disposal site locations |
| Estonia | - groundwater extraction and recharge |
| Finland | |
| Germany | |
| - Bavaria | - recording of abstraction, groundwaterheads/piezometric levels, temperature, quality |
| - Schleswig-Holstein | - recording of abstraction, groundwater levels/piezometric levels |
| - Rhineland-Palatinate | - pumping tests, groundwater models, groundwater monitoring |
| Hungary | - information on the state of the groundwater from both quantitative and qualitative aspects<br>- data of all kind of water uses.<br>- additional information on hydrometeorological characteristic |
| Lithuania | - data of groundwater quality |
| The Netherlands | - data of quality and quantity of groundwater: to show trends in groundwater quality and quantity changes, to provide a 3D picture of the groundwater quality and to provide early warning in case of standard exceeding |
| Moldavia | - more detailed and valuable information on the state of groundwater<br>- possibility and perspective of the exploration |
| Portugal | - information concerning quantitative and qualitative aspects of groundwater |
| Romania | - groundwater resources assessment<br>- volume and quality of water abstracted<br>- withdrawel permitted according with groundwater resources assessed<br>- evolution of quality of water on a long time period<br>- sources of groundwater pollution |
| Slovak Republic | - sources of groundwater pollution<br>- quantity and quality characteristics of groundwater resources |
| Slovenia | - demands of water supply (drinking water and technological water)<br>- the quantity an quality of groundwater source<br>- the discharge of groundwater<br>- the geological, hydrological and other physical conditions |
| Spain | - landuse, demands and uses, groundwater levels and quality data, saltwater intrusion |
| Switzerland | |
| The Ukraine | - information on long-term economic development of neighbouring countries<br>- harmonisation of monitoring systems of neighbouring countries |
| United Kingdom | |

## 5 The use of indicators

| | **Indicators** |
|---|---|
| Austria | |
| Belarus | - groundwater levels, discharge, temperature, quality |
| Bulgaria | - groundwater table (piezometric head), groundwater abstraction and flow rate of springs<br>- groundwater quality determinants: major ions, heavy metals, nitrogen compounds, pH, DO, BOD 5 |
| Croatia | |
| Czech Republic | |
| Estonia | |
| Finland | - groundwater monitoring (quality/quantity) systems concerning natural areas and water supply areas |
| Germany | |
| - Bavaria | - not up to now |
| - Schleswig-Holstein | - not up to now |
| - Rhineland-Palatinate | - groundwater levels, ecological reservation areas (flora) |
| Hungary | - groundwater levels, discharge of springs and small water courses<br>- chemical parameters, incl. environmental isotopes |
| Lithuania | - chemistry plus nutrients: volatile organic compounds, trace elements, chlorides, sulphates and nitrate |
| The Netherlands | - *eutrophication*<br>indicators will be developed which has a connection with the system of mineral declaration. The concentrations of nutrients in the groundwater are used as indicators for eutrophication. Periodic measurements of the emission and deposition amounts of ammoni-um will also be used as indicators for the eutrophication policy.<br>- *acidification*<br>emission and deposition of acidifying compounds. The presence of these compounds in the groundwater is an indicator for acidification.<br>- *dispersion*<br>indicators will be developed for emission to soil, water and air and for the degree of dependence of these substances. Concentration of heavy metals and volatile organic compounds are indicators for the state of the groundwater.<br>- *desiccation*<br>existence of plant species (vanishing or coming up) at a certain location are used as an indicator for changes in the groundwater table. The amount of groundwater abstraction and the groundwater table by itself are also used as indicators for desiccation. |
| Moldavia | - in percent, due to the economical situation, it is difficult to use any indicators |
| Portugal | |
| Romania | |
| Slovak Republic | |
| Slovenia | |
| Switzerland | |
| The Ukraine | - concentrations of pollutants in groundwater; ratios of pollutant concentrations in groundwater and back-ground or early industrial contents<br>- compliance of pollutant content with the norm and standards for drinking water.<br>- information on times and places of pollution events are sufficient for calculations, simulations and forecasts on regional and local level |
| United Kingdom | |